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# Distillation: Scale Considerations

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Boiler Water Essentials

Wearable Technologies

Crystallization

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Access Intelligence

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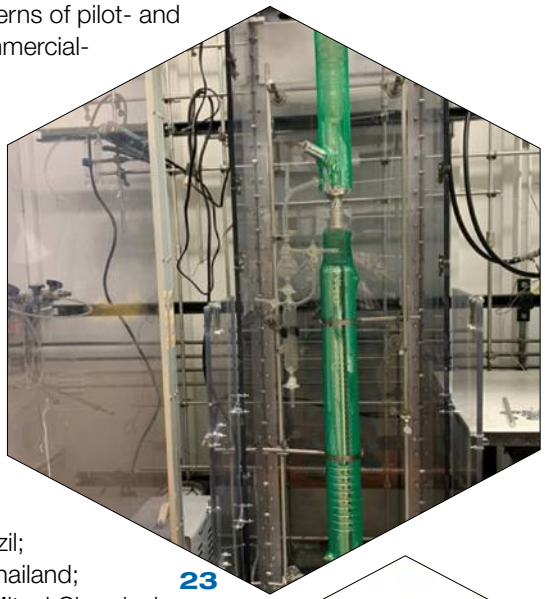

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# Editor's Page

## Driving change through funding

The U.S. Inflation Reduction Act of 2022 (IRA), which was passed into law last August, directs federal funding to a variety of sectors in the forms of grants, loans and tax incentives for corporations, and to a lesser extent to consumers. Significant amounts of the funding are directed to manufacturing and innovations that advance "clean energy" and decarbonization. The IRA is already having a noticeable impact on driving technological developments, as can be seen in the number of project announcements that cite IRA funding.

### Energy

Momentum for developing low-carbon energy is picking up, and many current developments cite federal funding as a strong supporting factor. Recent announcements include developing low-carbon hydrogen production, sustainable aviation fuels, batteries, fuel cells, carbon capture and more. Examples include: Linde (www.linde.com) plans to invest $1.8 billion to supply clean hydrogen to OCI's (www.oci.nl) blue ammonia project in Texas; LG Chem (www.lgchem.com) plans a $3-billion cathode plant in Tennessee; and Plug Power (www.plugpower.com) and Johnson Matthey (www.matthey.com) have partnered to advance the "green hydrogen" economy and plan to co-invest in what is expected to be the largest catalyst-coated membranes facility in the world. More information can be found on our website (www.chemengonline.com).

### Construction materials

While much attention is on the energy transition, another area that is poised to benefit from federal funding is the advancement of lower-carbon cement production. Cement processing is a major source of $CO_2$ emissions and demand for cement is expected to increase, particularly with the passing of the U.S. Infrastructure Investments and Jobs Act. The American Council for an Energy-Efficient Economy (ACEEE; www.aceee.org) says that technologies for low-carbon cement production are ready for market expansion and that funding from the IRA may accelerate their commercialization.

One development announced just last month was the capture of $CO_2$ via direct air capture (DAC) and its subsequent permanent storage in concrete. The demonstration project led by CarbonCure Technologies (www.carboncure.com) and Heirloom (www.heirloomcarbon.com), is said to be the first such achievement. Heirloom reportedly used its DAC technology to capture $CO_2$ from the atmosphere, after which CarbonCure's reclaimed water technology was used to inject the captured $CO_2$ into wastewater, which was then used to make concrete. The $CO_2$ is said to be durably sequestered in the concrete as calcium carbonate. The companies say that DAC technologies have recently received large investments from the IRA, as well as from the Department of Energy's DAC hub program (www.energy.gov).

To further encourage advancements in reducing greenhouse-gas emissions associated with the production and use of construction materials, such as cement, the Environmental Protection Agency (EPA; www.epa.gov) recently announced new programs made possible by a $350-million investment from the IRA. The EPA is currently seeking public input on establishing these programs. Three public engagement webinars will be held in March and April. More information about the programs and webinars can be found on the EPA's website. ■

*Dorothy Lozowski, Editorial Director*

## This coating boosts the efficiency of perovskite solar cells

Perovskite materials have great potential as a lightweight and low-cost option for solar panels, but in the past have not been seen as stable or durable enough for widespread use in large-scale solar-power installations. Now, a new coating developed by a research team at Purdue University (West Lafayette, Ind.; www.purdue.edu), led by chemical engineering professor Letian Dou, could overcome these challenges. "Perovskite can degrade quickly when exposed to moisture, heat or light, which limits its commercial application. Our organic ligand coating can reduce perovskite defects and passivate the surface, making the material much more stable. At the same time, the organic ligand can act as a semiconductor to help conduct charge, which helps to improve electrical performance," explains Dou.

While much work has been done to develop coatings to protect and passivate perovskite, many of these options focused on insulating materials that actually decreased charge transport, adds Dou. The ligand is a bipolar, conjugated molecule — one end is charged to bind with the perovskite, while is the other is hydrophobic to protect against moisture. To form the coating, the ligand is dissolved in a solvent at a dilute concentration (typically less than 1 mg/mL). According to Dou, the cost to manufacture the ligand is very low, and based on well-established methods. Furthermore, the perovskite surface only requires a very thin coating — just 4–5 nm — meaning that the coating would not add significant cost to solar panels.

Over a 2,000-h testing period at high heat, the coated panel maintained over 80% of its original power conversion efficiency. "This is much higher performance than the control device without the ligand coating," says Dou. Next, the team is considering ligands with new functional moieties and multiple binding sites to further enhance stability, and investigating ways to enhance solubility and processability to improve coverage. They also have a contract with a major solar-power company to begin testing the technology.

Edited by:
**Gerald Ondrey**

### ODC TECHNOLOGY

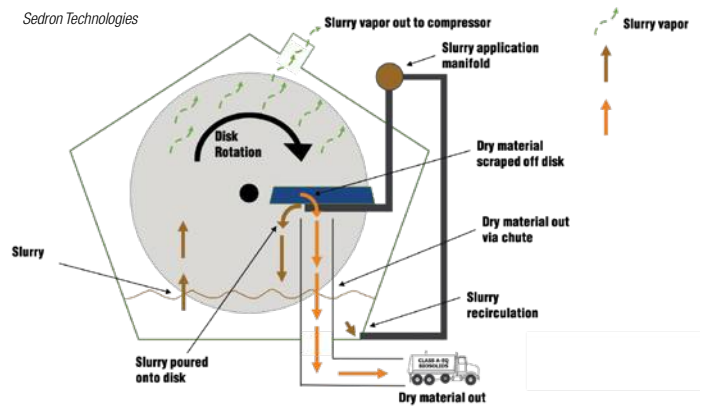
Last month, Covestro AG (Leverkusen, Germany; www.covestro.com) started up a new world-scale facility for the production of chlorine in Tarragona, Spain. It is the first world-scale production plant for chlorine based upon the oxygen-depolarized cathode (ODC) technology invented by Covestro and its partners. The new plant ensures an efficient, sustainable and independent supply of chlorine and caustic soda to methylene diphenyl diisocyanate (MDI) production in Tarragona. MDI is a precursor for the manufacture of rigid polyurethane foam used to insulate refrigeration appliances and buildings. The €200-million investment has created 50 new jobs on site.

The ODC technology was developed by Covestro in collaboration with thyssenkrupp nucera (Dortmund, Germany; www.thyssenkrupp-nucera.com), with the first demonstration plant started up in 2011 in Krefeld-Uerdingen, Germany (*Chem. Eng.*, May 2010, p. 11). Compared to the currently predominant conventional

(Continues on p. 8)

## Perform dewatering, drying and cleaning of liquid waste in a single process

A recently commissioned, 150,000-ton/yr facility in Sumner, Wash. is the first wastewater-treatment plant to deploy a new liquid-waste treatment technology. Owned by Generate Upcycle (San Francisco, Calif.; www.generatecapital.com), and operated in partnership with Sedron Technologies, LLC (Sedro-Woolley, Wash.; www.sedron.com), the facility treats septage- and biosolids-laden slurry using Sedron's Varcor technology to split the waste into clean water, a dry solid and a solution of low-boiling-point constituents, such as ammonia, explains Stanley Janicki, chief revenue officer at Sedron Technologies. "A Varcor system is unique, in that it replaces four traditional systems in a wastewater-treatment plant — dewatering, drying and sidestream nutrient removal for nitrogen and phosphorus — while ensuring that the energy source is electricity, making the process easily decarbonized," adds Janicki.




The process combines mechanical vapor recompression and distillation with thin-film and scraped-surface drying on a series of hollow rotating disks (diagram). Slurry is poured over the outside of the disks, and solids collect on the disk while the vaporized portion is sent for compression. The higher-temperature compressed vapor is passed back through the inside of the disks and condensed, providing the heat needed to continue to vaporize the slurry product. Because of this configuration, the system requires little heat input and no treatment chemicals. Notably, the water produced from the Varcor system is clean enough to be blended with the plant's effluent water, which significantly reduces the overall load on the plant.

Furthermore, the process yields both solid and aqueous nitrogen fertilizers, which can be upcycled as key agricultural inputs, explains Bill Caesar, president of Generate Upcycle. "The ability to extract nitrogen allows the Sumner facility to reduce nutrient pollution by diverting hundreds of thousands of pounds of nitrogen from existing wastewater plants and producing a fertilizer that displaces the production of fossil fuel-derived fertilizers," he adds.

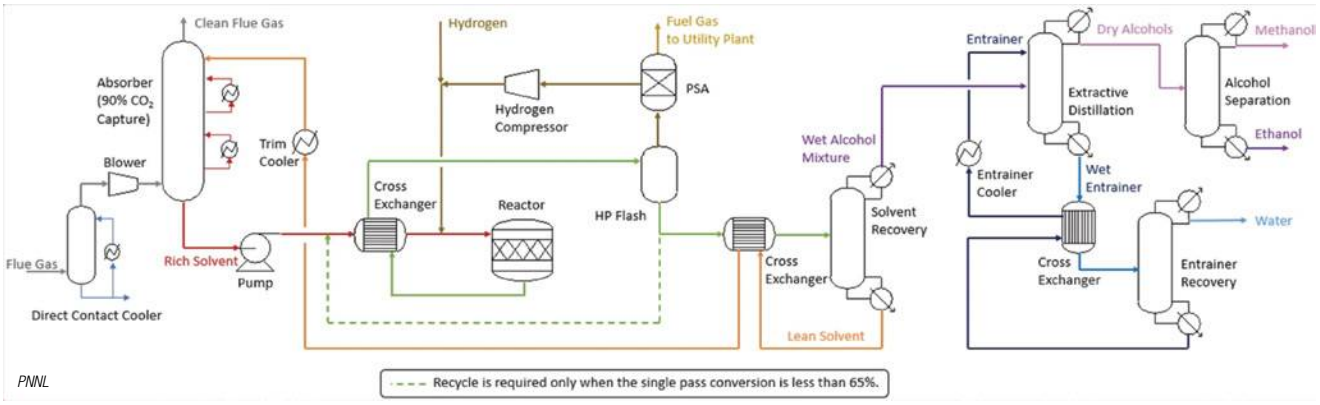
## Integrated capture and conversion of $CO_2$ to methanol

Processes that capture carbon dioxide from industrial fluegas and simultaneously convert it into useful chemicals are desirable because they offer an opportunity to produce $CO_2$-derived chemicals more efficiently and economically than conventional approaches, where costs are driven up by the energy-intensive regeneration of the capture solvent. By integrating $CO_2$ capture with conversion to methanol (flowsheet), scientists at Pacific Northwest National Laboratory (PNNL; Richland, Wash.; www.pnnl.gov) have developed a process that could eventually reach cost parity with producing methanol derived from fossil fuels, the PNNL team says.

For the $CO_2$ capture component, the team used 2-EEMPA (N-(2-ethoxyethyl)-3-morpholinopropan-1-amine), an advanced, water-lean, amine-based capture solvent. To produce methanol, the $CO_2$-containing solvent is exposed to a catalyst that consists of platinum metal atoms on a titanium-oxide support. The heterogeneous catalyst allows a reaction pathway that avoids methylation (and thus deactivation) of the capture solvent. Other catalysts used for methanol synthesis in the gas phase tend to deactivate the capture solvent by promoting a route that methylates the amine site.

With an integrated capture and conversion process, the exothermic $CO_2$-to-methanol conversion process partially offsets the energy that would normally be required in conventional carbon capture and utilization for the regeneration of the capture solvent, the PNNL team explains. Further, "because the captured $CO_2$ is converted directly in the capture-solvent medium, there is also energy saved on the $CO_2$ compression and transportation that would otherwise be required with gas-phase conversion, thus reducing additional energy inputs and associated equipment costs," PNNL says.

The PNNL research, reported in the journal *Advanced Energy Materials*, includes a technoeconomic analysis (TEA) of capturing $CO_2$ from a natural-gas combined-cycle power plant and converting it to methanol in the condensed phase. The TEA suggests that the minimum selling price for methanol can be significantly reduced, and may reach price parity with conventional methanol synthesis, if faster kinetics and higher selectivity can be achieved through catalyst and reactor development. Current efforts are focused in those areas, the PNNL team says.




## A new way to improve valve resiliency against flashing

Flashing occurs when the pressure of a fluid passing through a valve is lower than the same substance's vapor pressure. This causes the fluid to boil — otherwise known as "flashing." "By reducing flow capacity and eroding the valve itself, flashing causes unplanned maintenance, reduced reliability and critical safety risks," says Mike Semens-Flanagan, Global Engineering Director at IMI Critical Engineering (Birmingham, U.K.; www.imi-critical.com). The company has therefore developed a new valve enhancement technology called EroSolve Flashing, which aims to protect angle and globe valves against leakage and other issues caused by steam flashing. The EroSolve solution prevents low-travel operation and moves the fluid-path's *vena contracta* downstream of the seating area of the valve, effectively protecting it against any damage. It also gradually reduces pressure through the introduction of special multi-path, right-angle-turned flow passages that prevent sudden acceleration of fluid velocity.

In angle valves, hardened trim material and an enhanced seat-plug design move flashing away from vital trim parts, and enable the valve to withstand severe conditions. The EroSolve variant designed for globe valves employs a seat basket that creates backpressure to reduce downstream velocity and pressure drop to avoid damage to the valve body — without requiring any piping modifications.

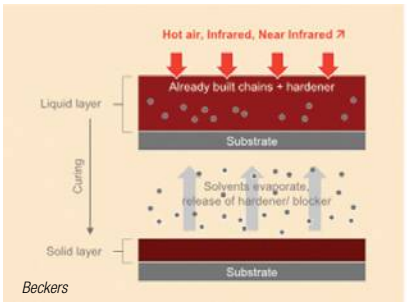
According to the company, this is the first dedicated and successfully demonstrated valve technology on the market aimed at mitigating problems related to flashing. EroSolve Flashing has been demonstrated in a combined-cycle power plant that had experienced erosion in its heat-recovery steam generators (HSRGs). Following the installation of valves equipped with EroSolve technology, there was no component damage reported after a year. In another demonstration, EroSolve valves were installed at a chemical plant in South Korea to replace boiler blowdown valves whose trim had not been specified for flashing conditions. The new valves are expected to last 2 to 4 times longer than the previous valves, resulting in a significantly lower cost of ownership, says the company.

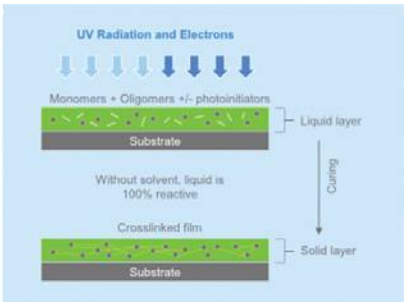
# More sustainable curing technology for coil coatings

Coil coating is a continuous process for producing prepainted sheets of metal (steel or aluminum), which can then be fabricated into various building and other materials. Because organic coating materials are used, the process requires substantial energy for the curing and drying steps, and can generate significant emissions of volatile organic compounds (VOCs). To make the curing process more sustainable, efforts to find alternatives to traditional thermal-curing processes (diagram, left). The European Coil Coating Assn. (ECCA; Brussels, Belgium; prepaintedmetal.eu) considers ultraviolet (UV) and electron-beam (EB) curing technology to be the most significant game changer in terms of decarbonization of the coil coating industry.

Now, Wilh. Beckers Holding GmbH (Berlin, Germany; www.beckers-group.com) has developed the first commercial paint formulations for dual UV and EB curing (diagram, right). Until now, the only available industrial application of radiation curing in coil coating has been EB irradiation used for packaging material. Long-term collaboration between Beckers and one of its customers has led to the first ever full-scale application of advanced, dual-UV/EB-curing technology in coil coating for the building industry.

At Beckers' development laboratory in Montbrison, France, a team of researchers has demonstrated that UV/EB curing has significant potential to reduce the $CO_2$ footprint of coil coating, due to the fact that it requires much less paint and energy in the curing process. "UV/EB curing allows us to use up to 100% solid, solvent-free formulations that are more efficient and provide up to twice the surface coverage per kilogram of paint," says Gavin Bown, CTO at Beckers. Solid, solvent-free UV/EB paint formulations are more sustainable, because around half the volume of paint is needed and they significantly reduce VOCs. "Compared with conventional gas-fired curing, the UV/EB cold-curing process also uses much less energy, facilitates the transition from natural gas to renewable electricity, avoids the use of expensive gas, and does not require water for cooling," says Bown. Because the UV/EB curing process is almost instantaneous, coating lines can be shorter and run at higher speeds.

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chlor-alkali electrolysis, the new process requires a lower voltage, which results in energy savings of up to 25% (for more details, see *Chem. Eng.*, October 2018, p. 7). At the new plant in Tarragona, this can avoid up to 22,000 metric tons of $CO_2$ emissions per year compared with existing processes — based on the energy mix at the start of construction planning in 2018, Covestro says.

### AUTONOMOUS SYNTHESIS

Last month, Alysophil ASA (Strasbourg, France; www.alysophil.com) said it has demonstrated the world's first autonomous chemical synthesis, using a continuous-flow reactor controlled by an artificial intelligence (AI) agent (algorithm) known as deep-reinforcement learning (DRL). This proof-of-concept is a milestone of the PIPAc (Production Intelligente de Principes Actifs) project, which aims to develop microfactories for producing active pharmaceutical ingredients (APIs). The project, which is backed by investment firm Bpifrance with funding from the French government, includes partners NovAliX SAS (www.novalix.com), Bruker (www.bruker.com) and De Dietrich Process Systems SAS (www.dedietrich.com).

The technology takes the advantages of flow chemistry one step further, by adapting synthesis parameters, such as temperature and flowrate, in real time using AI. Continuous monitoring using Fourier-transform infrared (FTIR) spectroscopy and other sensors collects the data used by the AI agent.

The PIPAc consortium demonstrated a single-step reaction of dioxolane synthesis at 60°C, as well as adaptability of the system when the temperature drops to 40°C. It aims to deliver an industrial demonstrator by 2024 and have a fully operating micro-plant by 2025.

### SUSTAINABLE SILICA

Solvay S.A. (Brussels, Belgium; www.solvay.com) is investing at its Livorno site, in Italy, to launch the company's first unit of circular highly dispersible silica (HDS), which is made with

(Continues on p. 9)

## A new high-throughput tool for developing catalysts

When searching for catalysts for the energy transition, materials consisting of at least five elements — so-called high-entropy alloys (HEAs) — are considered highly promising. But to find the right combination of elements and composition ratios needed for the best activity is difficult, since there are theoretically millions of possibilities. To help speed the discovery of better electrocatalysts, a research team, led by professor Alfred Ludwig, head of the Materials Discovery and Interfaces Department (MDI) at Ruhr University Bochum (Germany; www.rub.de), has succeeded in producing microscale combinatorial libraries of all possible combinations of five elements on a carrier in a single step. The researchers also developed a method to analyze the electrocatalytic potential of each of the combinations in this micromaterial library in high throughput.

As described in a recent issue of *Advanced Materials*, the researchers were able to create microlibraries for two HEA systems: Ru–Rh–Pd–Ir–Pt and Co–Ni–Mo–Pd–Pt. They also were able to find the optimal combinations of elements in these HEAs for the three important electrocatalytic reactions: the hydrogen evolution reaction (HER), the oxygen evolution reduction reaction (ORR) and the oxygen evolution reaction (OER).

To create the microlibraries, the researchers used a process that combines co-sputtering with a shadow-masking technique, which enabled all combinations of the five elements to be fabricated onto a single carrier. Each individual material mixture appears as a 100-µm dia. spot on the carrier. To study these material libraries, a technique known as scanning electrochemical cell microscopy was used. This involves measuring the electrochemical properties of the material at a specific point via a hanging nanodroplet of an electrolyte.

The technique promises to help chemists quickly discover promising catalysts for further study.

## Battery electrode binder allows easier recycling

Recovering valuable metals, such as cobalt and nickel, from used lithium-ion batteries is emerging as a key capability because of anticipated high battery demand and material shortages. Researchers at Lawrence Berkeley National Laboratory (Berkeley, Calif.; www.lbl.gov) have developed a technology for an electrode binder material that facilitates the recovery of valuable metals from used batteries at low cost. Binders are glue-like substances that hold the active materials together within the electrode and maintain its architecture.

To make new batteries, manufacturers process binders with solvents to create a slurry containing all the electrode components, which is then deposited in the desired shape and thickness on electrode sheets. The Berkeley Lab approach was to "design for recycling" in the way the electrode is made.

Known as Quick-Release Binder, the Berkeley Lab product is made from two commercially available polymers, polyacrylic acid (PAA) and polyethylenimine (PEI), that are joined together through a bond between positively charged nitrogen atoms in PEI and negatively charged oxygen atoms in PAA. When the solid binder material is placed in alkaline water containing sodium hydroxide, the sodium ion inserts into the bond site, breaking the two polymers apart. The separated polymers dissolve into the liquid, freeing any electrode components embedded within.

"A battery made with Quick-Release Binder simply needs to be opened, placed in room-temperature alkaline water, and gently shaken," says project leader Gao Liu, a senior scientist in Berkeley Lab's Energy Technologies Area. "The separated elements are easily filtered out of the water and air-dried."

The binder, which contains no PFAS compounds and can be used to make both anodes and cathodes, is about one-tenth the price of two of the most commonly used commercial binders. Past experiments demonstrated that the binder is highly stable at high and low voltages.

The Quick-Release Binder originated from research on lithium-sulfur batteries, which are possible future alternatives to traditional Li-ion batteries, and later applied to Li-ion batteries. The team is now working with Steve Sloop, a battery recycling developer and founder of OnTo Technologies (Budd Lake, N.J.; www.ontotechnology.com) to build prototype Li-ion batteries with the Quick-Release binder to analyze its performance comprehensively and showcase its functionality.

## Sorption-enhanced methanation

The production of substitute (or synthetic) natural gas (SNG) by methanation of $CO_2$ with hydrogen is energy intensive and also requires a purification step to remove the byproduct water and remaining reactants. To address these issues, researchers at The Swiss Federal Laboratories for Materials Science and Technology (Empa; Dübendorf, Switzerland; www.empa.ch) have developed a new, optimized reactor concept for methanation.

The new concept uses a process called sorption-enhanced methanation. $H_2$ and $CO_2$ are fed to a fixed-bed reactor containing nickel-impregnated porous zeolite pellets as catalyst. As the reaction proceeds, byproduct water is continuously adsorbed by the zeolite, which shifts the reaction equilibrium toward the products. At the outlet of the reactor, only $CH_4$ remains, which can be used without further purification. The water is then removed from the zeolite by flushing the reactor with $H_2$, and another batch can begin.

"This process is more flexible and stable than previous processes, but it also has some potential for energy savings because we can run it at a lower pressure and do without hydrogen separation and recirculation," explains project leader Florian Kiefer. "However, a precise assessment of the energy efficiency will only be possible once the demonstrator is in full operation," he says. An industrial-scale process would require at least two reactors alternating in parallel.

Kiefer and his team spent around three years developing this reactor concept, in collaboration with industrial partners, as part of project MEGA within Empa's "move" demonstrator for the mobility of the future. A patent has been filed. ■

bio-based sodium silicate derived from rice-husk ash. This new silicate process provides a circular solution, as it gives a second life to rice husk in a local value chain. Coupled with renewable-energy integration at the plant, it will allow Solvay to achieve a 50% reduction in $CO_2$ per ton of silica. Production is expected to start by the end of 2024.

Solvay will gradually replace its existing Zeosil portfolio with circular HDS, providing a circular solution for tires, as well as addressing the needs of the home- and personal-care, and the feed and food industries. Solvay also plans to build a new plant in North America over the coming years, and is investigating projects in circular HDS in Asia and South America.

### CARBON FIBER RECOVERY

Asahi Kasei (Tokyo; www.asahi-kasei.com), in collaboration with the National Institute of Technology, Kitakyushu College and Tokyo University of Science (all Japan), has developed a new technology for recycling carbon-fiber plastic compounds. The new technology — electrolyzed sulfuric acid solution — allows carbon fibers to be extracted from carbon-fiber reinforced plastics or thermoplastics (CFRP or CFRTP). Unlike alternative recycling methods that chop up the materials to give short-length carbon fibers that are only suitable for low-performance materials, the new process extracts carbon fibers seamlessly, resulting in a continuous strand that can be reapplied in exactly the same manner, while retaining properties identical to the original substance. ❐

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## Plant Watch

### Arlanxeo starts up new polybutadiene production line in Brazil

February 14, 2023 — Arlanxeo B.V. (Maastricht, the Netherlands; www.arlanxeo.com) opened a new polybutadiene production line in Brazil. The new production line supplements Arlanxeo's existing production capacity in Brazil with an additional 65,000 metric tons per year (m.t./yr) of capacity. The new production line is located in the Triunfo petrochemical complex in Rio Grande do Sul.

### Indorama India commences production at third spandex production plant

February 14, 2023 — Indorama India Ltd. (Kolkata, India; www.inviya.com) commenced commercial production of its third manufacturing facility for spandex (elastane) at Baddi in Himachal Pradesh. This plant adds 25 m.t./d of spandex production capacity, bringing the total production at the site to 65 m.t./d.

### Kuraray completes construction of new isoprenes plant in Thailand

February 9, 2023 — Kuraray Co. (Tokyo; www.kuraray.com) has completed the construction of a new plant for isoprene products. The new facilities have been designed to produce 13,000 m.t./yr of polyamide-9T, 16,000 m.t./yr of hydrogenated styrenic-block copolymers and 5,000 m.t./yr of 3-methyl-1.5-pentanediol. The company invested around ¥40 billion ($310 million) in the project.

### Merck breaks ground for specialty-gases and semiconductor-materials plant

February 8, 2023 — Merck KGaA (Darmstadt, Germany; www.merckgroup.com) broke ground in Kaohsiung, Taiwan for a new production facility for its Semiconductor Solutions business. The site will produce specialty gases and semiconductor materials for thin-film and patterning solutions beginning in 2025.

### Toray to expand production capacity for PPS resin in South Korea

February 6, 2023 — Toray Industries, Inc. (Tokyo; www.toray.com) will increase its production capacity for polyphenylene sulfide (PPS) resin by 5,000 m.t./yr at a plant in Gunsan, South Korea, by late 2024. With this expansion, Toray's combined PPS manufacturing capacity will rise to 32,600 m.t./yr.

### Repsol to install new manufacturing line for recycled plastics

February 2, 2023 — Repsol S.A. (Madrid, Spain; www.repsol.com) will install a new recycled-plastics production line with a manufacturing capacity of 25,000 m.t./yr at its Puertollano Industrial Complex in Spain. The new unit, which will begin operation at the end of 2024, will almost double the current capacity. With an investment of €26 million, it will manufacture plastics used to produce rigid and flexible packaging for non-food use. Specifically, it will process high- and low-density polyethylene (HDPE and LDPE) with recycled plastic content. In addition to the new recycled-plastic production line, Puertollano will start up the first polyurethane-foam-recovery plant in Spain this year.

### Elkem to expand pitch production capacity in Brazil

February 1, 2023 — Elkem ASA (Oslo, Norway; www.elkem.com) will invest around NOK 200 million (around $20 million) to increase its production capacity in Brazil for pitch, a raw material for electrode paste to industrial smelters. The investment will increase the production capacity by up to 40% beginning in 2024, and is expected to generate additional annual sales in excess of NOK 300 million.

### Evonik to expand production capacity of methylmercapto-propionaldehyde

February 1, 2023 — Evonik Industries (Essen, Germany) has invested €25 million in developing and expanding its methylmercapto-propionaldehyde (MMP) production plant in Wesseling, Germany. MMP is integral in the production of DL-methionine, which is used in animal feed to improve the performance of livestock farming. The conversion and expansion of the plant in Wesseling has been made possible by the development of a new production process that eliminates the need for storage of chemical intermediates, such as acrolein, at the site.

### Linde to increase green-hydrogen production in California

January 31, 2023 — Linde plc (Guildford, U.K.; www.linde.com) plans to increase its green-hydrogen production capacity in Ontario, Calif. Linde will build, own and operate the first of several planned 5-MW electrolyzers to increase hydrogen capacity. Expected to start up in the second half of 2024, the new electrolyzer is one of several green-hydrogen projects Linde is planning across the U.S.

### ALPLA opens new PET recycling plant in Romania

January 31, 2023 — ALPLA Group (Hard, Austria; www.alpla.com), together with its joint-venture partners Ecohelp and UPT, has opened its first polyethylene terephthalate (PET) recycling plant in Romania after an investment of around €7.5 million. The plant is now producing around 18,000 m.t./yr of recycled material from household waste.

## Mergers & Acquisitions

**Mitsui Chemicals and Asahi Kasei combine nonwovens businesses**

February 9, 2023 — Mitsui Chemicals, Inc. (www.mitsuichemicals.com) intends to carry out a joint incorporation-type demerger with Asahi Kasei Corp. (both Tokyo; www.asahi-kasei.com) for the two companies' nonwovens businesses, forming a new integrated company. The business integration agreement aims to carry on the operations that both companies run in Japan and Thailand for the production, development and sale of nonwovens-related products.

**AGC and Saint-Gobain collaborating on decarbonization**

February 8, 2023 — AGC Inc. (Tokyo; www.agc.com) and Saint-Gobain Corp. (Courbevoie, France; www.saint-gobain.com) are collaborating on the design of a pilot flat-glass production line that is expected to significantly reduce direct $CO_2$ emissions. As part of this project, AGC's patterned-glass production line in Barevka, Czech Republic, will be entirely refurbished to be 50% electrified and 50% fired by a combination of oxygen and gas. The new technology is expected to be fully implemented on the patterned-glass line by the second half of 2024.

**Eastman acquires performance films company Ai-Red Technology**

February 2, 2023 — Eastman Chemical Co. (Kingsport, Tenn.; www.eastman.com) has acquired Ai-Red Technology (Dalian) Co., a manufacturer and supplier of paint-protection and window-film technologies in the Asia-Pacific region.

**Plug Power and Johnson Matthey form green-hydrogen alliance**

January 31, 2023 — Plug Power Inc. (Latham, N.Y.; www.plugpower.com) and Johnson Matthey plc (JM; London; www.matthey.com) formed a long-term strategic partnership to accelerate the hydrogen economy. JM will become a strategic supplier of membrane components, providing a substantial portion of Plug's demand for catalysts, membranes and catalyst-coated membrane (CCM) technologies. Plug Power and JM will co-invest in what is expected to be the largest CCM manufacturing facility in the world, which will likely begin production in 2025 and will be located in the U.S.

**Sumitomo Chemical acquires U.S.-based biostimulants firm**

January 31, 2023 — Sumitomo Chemical Co. (Tokyo, Japan; www.sumitomo-chem.co.jp) is acquiring Tennessee-based biostimulant manufacturing firm FBSciences Holdings, Inc. FBS develops, manufactures and markets biostimulants and biopesticides made from natural organic matter.

**Kemira acquires process-optimization startup SimAnalytics**

January 26, 2023 — Kemira Oyj (Helsinki, Finland; www.kemira.com) acquired the entirety of process-optimization specialist SimAnalytics. With the acquisition, Kemira strengthens its capability to provide data-driven predictive services and machine-learning solutions. The two companies currently offer a commercialized digital service that helps paper and board mills run production more efficiently. ■

*Mary Page Bailey*

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# Head to Toe Technology: Advances in Wearables

From headsets to gloves to fabric sensors, technologies that can be worn on the body are providing many new benefits for plant workers

Apace with innovations in all "smart" technologies, wearable devices for industrial personnel are rapidly evolving to incorporate enhanced connectivity, bioresponsive behavior, augmented reality and more.

## Expanding what we see

In chemical plants, engineers and operators often must perform inspection and measurement tasks in cramped, dark or dangerous locations. Now, a new device developed by a team of researchers from the Rolls-Royce University Technology Center (UTC) in Manufacturing and On-Wing Technology at the University of Nottingham (www.nottingham.ac.uk/utc), in cooperation with Rolls-Royce plc (Derby, U.K.; www.rolls-royce.com), aims to make these activities safer and more effective by enabling users to "see" with their hands. The EyeGlove system (Figure 1) comprises several tiny cameras mounted on the fingertips of a glove, along with a connected headset that can directly display inspection and measurement results.

"Conventional inspection tools, such as borescopes and endoscopes, usually have long passive sections, which are difficult to control in complex environments. Thanks to the flexibility and dexterity of human hands and arms, the EyeGlove's finger-mounted cameras can be easily controlled and posed," explains Dragos Axinte, director of the Rolls-Royce UTC. "Furthermore," says Axinte, "three high-power LED lights complement the cameras, making the EyeGlove adaptable for use in dark environments."

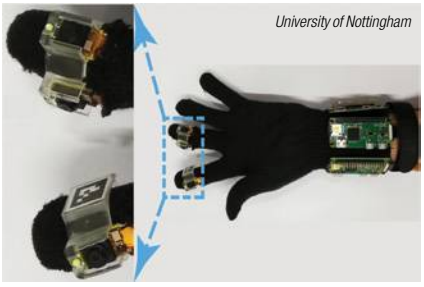



**FIGURE 1. The EyeGlove system involves tiny cameras that are mounted on the fingertips of gloves, enabling inspection and measurement in confined, dark spaces**

"By wearing the EyeGlove system, operators' hands can be freed to hold and manipulate repair tools, such as spanners, files and rasps, or other inspection tools, such as ultrasonic or eddy-current probes. This enables operators to accomplish more tasks at the same time," adds Xin Dong, associate professor at the University of Nottingham. The research team, led by Axinte, has demonstrated prototype EyeGlove systems in several confined scenarios, such as turbine engines and pipelines (Figure 2), and tested measurement accuracy in different lighting conditions.

"In addition to confined environments, large-scale open areas are widely encountered in chemical plants, such as large vessels and high distillation units. Inspection in these spaces requires operators to climb above the ground, and it is difficult to bring a large and cumbersome inspection system. The EyeGlove system can be used to assist operators to easily inspect these spaces because of its flexibility and light weight," adds Erhui Sun, a research associate who originally developed the system.

Headsets and smart glasses can also provide "hands-free" access to process and equipment data beyond what the eye can see when in the field, but it is crucial that these devices are not too bulky or uncomfortable to wear. Rather, they should fit seamlessly with an engineer's typical

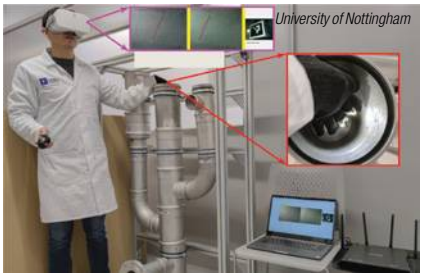



**FIGURE 2. Difficult-to-inspect spaces, such as pipelines and turbine internals, can benefit from the EyeGlove's versatility**

personal protective equipment (PPE). The Visor-EX 01 smart glasses (Figure 3), developed by ECOM Instruments GmbH, a Pepperl+Fuchs brand (Assamstadt, Germany; www.ecom-ex.com), were designed with wearability in mind by minimizing the amount of weight that must be balanced directly on the head. "By outsourcing much of the components for computing and energy supply to our Smart-Ex 02 smartphone and a pocket unit on the body, the Visor-Ex 01 glasses weigh just 180 g — unrivalled in industrial smart glasses," says Sebastian Kaul, product portfolio manager at ECOM Instruments. With the connected smartphone, users can seamlessly switch between tasks during activities that require additional information or continuous communication. A voice-command function also leaves hands free and adds freedom of movement, notes Kaul. "The intrinsically safe Visor-Ex 01 smart glasses are the first device of their kind to be certified according to ATEX and IECEx standards," he adds. During the development phase, the glasses underwent an extensive endurance test on an offshore oil platform. "With the help of cameras and image processing, QR codes from devices and machines could be read to gain access to sensor data, such as pump pressure. Our smart glasses improved the

**FIGURE 3. In addition to its intended functionality, any wearable device should also be designed for the wearer's comfort**

documentation of incidents not only quantitatively, but also qualitatively."

## Geolocation and mapping

A new frontier for wearable technologies is in mapping, location and scanning applications. The NavVis VLX wearable mobile mapping system (Figure 4) developed by NavVis GmbH (Munich, Germany; www.navvis.com) is said to enable up to 10 times faster data capture than terrestrial laser scanners, even in complex outdoor environments like chemical plants and petroleum refineries. "This makes it possible for projects to capture larger areas at earlier project phases," explains Nate Bridges, senior account executive at NavVis. The NavVis VLX captures data in three dimensions using two multi-layer light-detection and ranging (LiDAR) sensors and a proprietary simultaneous localization and mapping (SLAM) algorithm to develop point clouds (Figure 5). Whereas other scanning tools require significant training for users, the NavVis VLX system has built-in features to help mitigate human errors during data capture, and is compatible with industry-standard tools, adds Bridges. "The versatility offered by a wearable laser scanner like NavVis VLX allows the user to capture more complete datasets in some of the most complex environments while obtaining highly accurate point-cloud data and panoramic imagery, all without having as many personnel on site."

The NavVis VLX has been used in plants during conceptual planning, model verification, maintenance and turnarounds. "Turnaround management groups are utilizing NavVis VLX technology to digitalize their turnaround planning, and inspections divisions are managing their inspection points using 3D data captured with NavVis VLX," says Bridges. Henkel AG (Düsseldorf, Germany; www.henkel.com) used NavVis' technologies to create a complete digital copy of a manufacturing facility in Serbia, which engineers could remotely "visit" for inspection, optimization and training activities. This virtual plant was made possible by the use of wearable and wheel-mounted mapping systems.

Monitoring worker safety and health is one of the key drivers behind advancements in wearable devices. The Safety Watch real-time location-monitoring solution (RTLS) from Honeywell Process Solutions (HPS; Phoenix, Ariz.; process.honeywell.com) aims to help mitigate operational and safety risks by using radio-frequency identification (RFID) to monitor employee assigned location and fatigue, and identify when an employee enters a restricted area. Beyond employee health, the Smart Watch's geolocation capabilities provide benefits for security and emergency response, says Veronica Turner, industrial safety solutions leader for Latin America at HPS. "The old method of emergency mustering is that employees needed to approach a mustering area, and they typically would have to swipe their badge to get accounted. With this solution, they just need to approach the area and then a receiver will get the signal from their specific device and count them," she notes. According to Honeywell, Smart Watch use can reduce mustering time by up to 80% when compared to more manual processes. This functionality is especially useful during major events, such as turnarounds, when there could be hundreds of additional contractors on site who must be accounted for. For security, the platform can implement "virtual walls" within a plant site to minimize the number of people entering hazardous areas, or to ensure that there is no unauthorized entry to sensitive locations. "The platform can quickly create geo-fencing that can immediately start giving alerts based on company protocols. There is a lot of flexibility — you can block an area for a few hours during maintenance work, or you can permanently block certain areas," notes Turner. For personnel health and safety, the devices can detect falls, and include a "panic button" that sends a notification in the event of a serious incident.

## The industrial metaverse

A category of wearable devices that has been quickly gaining ground in industrial applications is headsets that support virtual reality (VR) or augmented reality (AR) technology platforms. Such headsets are just one facet in the burgeoning industrial "metaverse" — a term essentially encompassing the collaborative and connected, persistent virtual environment enabled by 3D digital twins. "People are getting somewhat hardwired that when we use the word 'metaverse,' that means we wear a headset," says Simon Bennett, global head of innovation and incubation at Aveva (Cambridge, U.K.; www.aveva.com). "But that's not how we perceive it at all. We think that we should be able to enter the metaverse on our laptop, phone or tablet as well, because the value of the metaverse is about connecting people and data."

Chemical processing facilities can benefit greatly from the virtual nature of the industrial metaverse because of the massive volumes of data that are constantly being collected, as well as the hazardous and sensitive nature of the products and processes that are encountered. "Every single item within a chemical processing environment is a live machine or process that needs to be tracked, and we should be able to interact with the data feeds coming from it," adds Bennett. "The metaverse provides an opportunity for specialists to meet together in a 3D space, but not a 3D space like a conference room. The 3D space is their actual asset."

In Aveva's industrial metaverse concept, people are able to enter a 3D model of a running chemical plant

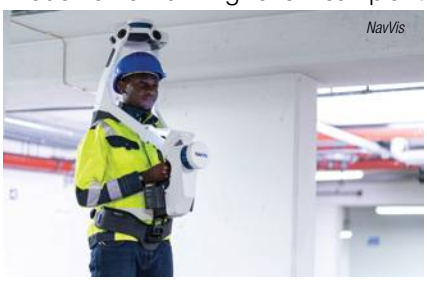



**FIGURE 4. This wearable system makes scanning and mapping facilities much more streamlined**

**FIGURE 5. The comprehensive datasets enabled by the point clouds that the NavVis system develops can be applied into full digital twins**

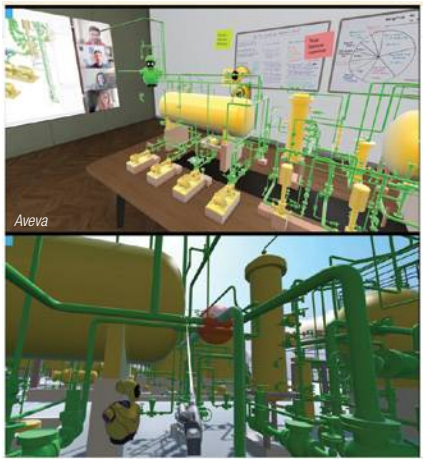



**FIGURE 6. The industrial metaverse concept envisions a VR-enabled, collaborative environment where workers can access live, digital versions of their assets**

and interact with the assets (Figure 6). "It's really different and a much more natural collaboration between people when you're in the 3D space. Neither of us have left our chair, but we are manifesting in a version of the actual operating asset," says Bennett. Safety considerations are obviously a huge factor when considering virtual collaboration, because no travel or special site certifications will be required to access an asset. "I don't need any safety certificates to fly my avatar to the top of a flare stack when I'm in the metaverse because there's no physical risk to me. There are definitely some opportunities to bring more expertise into high-risk environments more quickly," he adds.

However, a major hurdle for implementation of the industrial metaverse is overcoming preconceived notions about VR headsets. Bennett believes that headsets will become more ubiquitous among the younger workforce, citing a study that Aveva carried out with the University of Milan (www.unimi.it) looking at how chemical engineering and industrial-chemistry students benefitted from complementing their traditional education with virtual "visits" to simulated industrial environments. According to Bennett, the study found that students who had the more experiential aspect of using the headsets scored around 60 to 70% better than students who did not use headsets. "When you actually experience something, versus just reading about it, it's much more solid in your memory for recalling later. So, there is definite evidence that using headsets with full VR, specifically in the context of industrial chemists, has real value for them when they enter the workforce."

## Advanced functional materials

Progress in materials research and development is helping to expand the applicability of wearable technologies and overcome some of the challenges in designing functional wearables for industrial use.

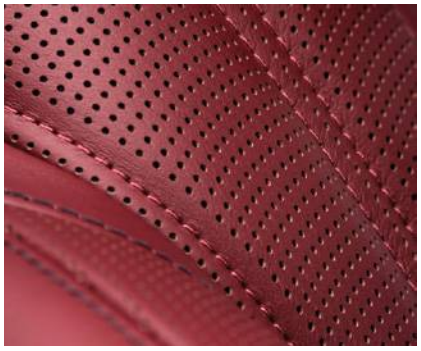
Dynamic pressure changes are a major hurdle in developing wearable sensors. As the wearer goes about their everyday tasks, the pressure on any device they are wearing is frequently changing, which can interrupt the flow of data from the sensor. Now, a new method of vapor-printing enables pressure-sensing fabrics with integrated piezoionic materials, which redistribute ions throughout the sensor, effectively turning any mechanical motion into an electrical signal that can be monitored. Developed at the University of Massachusetts Amherst's (www.umass.edu) Wearable Electronics Laboratory, this is said to be the first fabric-based sensor that allows real-time monitoring. "Fabric pressure sensors are useful in industrial PPE to indicate if a pressure threshold has been exceeded. For example, the destructive pressure from exceeding a recommended grip strength while moving or operating inventory or equipment in industrial settings," explains Trisha L. Andrew, director of the Wearable Electronics Laboratory. According to work published in *Advanced Materials Technologies*, this also represents the first fabric-based sensor that enables personalized real-time analysis of grip strength. Applications of the pressure sensors include capturing physiological signals in loose-fitting garments and gait in footwear, says Andrew. The sensors also feature a special coating to protect against humidity, meaning that fabrics can be easily laundered.

In another example of functional materials for wearables, scientists are using the *de novo* computational protein-design approach to develop new biosensors that can detect hazards and toxins. According to Fiorenzo Omenetto, dean for research and professor of engineering at Tufts University (Medford, Mass.; www.tufts.edu), the sensors represent a confluence of biomaterials (in this case a regenerated silk fibroin) and *de novo* protein constructs that can be reassembled into several wearable end formats while maintaining the protein's functionality. For this work, the team was able to fabricate the bioresponsive materials into a printable ink, wherein the protein constituent could be designed to respond to particular molecules of interest with high selectivity and specificity. The biosensor is programmed to glow when it detects its target molecule, and the intensity of light emission can be used to gauge the concentration. In addition to inks, the materials platform can be adapted into films, sponges, filters and more. The biosensors are also more durable than many existing methods for detecting pathogens or chemicals in the environment, since they require no biological components that can quickly degrade or electronic components that are difficult to integrate into wearable devices.

"We fabricated a set of functional demonstrator devices, including bioresponsive PPE, such as masks and laboratory gloves," says Omenetto. A key benefit for this materials platform is its versatility. In addition to the PPE demonstrations, the team has developed a bioresponsive drone prototype for air-quality monitoring. Such demonstrations, says Omenetto, are meant to illustrate the expanded utility and ease of fabrication for these sensing interfaces, even when targeting hard-to-detect variables. The Institute for Protein Design at the University of Washington (Seattle; www.ipd.uw.edu) engineered the proteins that the Tufts team incorporated into the devices. ■

*Mary Page Bailey*

# Focus on Process Chemicals



Lubrizol Engineered Polymers

DuPont

## This synthetic leather is durable and abrasion resistant

A prototype of the newly developed SilSense material for car seat covers (photo) was exhibited at the Auto Expo Components trade show (New Delhi, India; January 12–15). SilSense material is a non-animal synthetic leather that has low volatile organic compound (VOC) content, because it is produced through a solvent-free process that is cleaner than other products currently used in the market for vegan synthetic leather. The new material has a leather-feel soft touch and comfort, and it can be provided in different textures and colors. The greatest benefit is its high durability and performance, said to be better than genuine leather and much better than polyvinylchloride (PVC), the company says. SilSense also has a strong resistance to abrasion and tear, combined with an excellent heat and ultraviolet (UV) resistance. — *Lubrizol Engineered Polymers, Cleveland, Ohio*

**www.lubrizol.com**

## A new antioxidant and ultraviolet stabilizer

This company manufactures a comprehensive range of antioxidants and UV stabilizers in a full range of physical product forms. It recently expanded its portfolio with two new products: Songnox 9228 antioxidant and Songsorb 1164 UV absorber, which are suitable for packaging, agriculture, building and construction, as well as home and personal care applications. Due to its excellent hydrolytic stability, Songnox 9228 antioxidant overcomes the challenges traditional high-performance phosphites/phosphonites face by allowing more severe polyolefin processing, especially at high temperatures. In addition to this, it also delivers excellent color protection for Cr-type high-density polyethylene (HDPE), polypropylene (PP) and engineering resins. The latest addition to the company's range of UV absorbers is a triazine, Songsorb 1164 protects plastics against UV light degradation. Compared to conventional benzotriazole UV absorbers, Songsorb 1164 makes it possible to achieve a longer service lifetime for polyolefins and engineering plastics exposed to outdoor weathering. The product was developed to be suitable for polyolefins intended for use in contact with food. — *Songwon Industrial Co., Ltd., Ulsan, South Korea*

**www.songwon.com**

## This architectural fabric takes advantage of natural lighting

Last October, this company and Seaman Corp. (www.seamancorp.com) launched a new Shelter-Rite High Light Transmission architectural fabric (photo) using transparent Tedlar PVF film. This new architectural fabric is suitable for structures that require natural light, such as sports arenas, event venues and greenhouses. Transparent UV-blocking Tedlar film is a high-performance material that provides decades of durable protection. With excellent weatherability and dirt-shedding properties, Tedlar preserves the life and aesthetics of architectural fabric structures even in extremely harsh environments. It provides a high level of protection against UV light, moisture, rain and pollution. — *DuPont, Wilmington, Del.*

**www.dupont.com**

## New coatings for HVAC applications

Polydure coatings contain a proprietary resin technology specifically tailored to the needs of the heating, ventilation and air-conditioning (HVAC) segment, including commercial, industrial and residential applications. The proven coating system provides a trouble-free application combined with a consistent, smooth film. It contains excellent forming properties and provides batch consistency, along with a broad range of color, gloss and texture options. The Polydure portfolio includes focus-formulated primers as part of the coating system, allowing the topcoat to perform at an optimal level. The primers utilize formulation models for best-in-class performance, including UV stability, corrosion resistance, delamination and intercoat adhesion. In addition, they contain Dual Action

# EKATO Crystallizers for batch and continuous processes

Crystallization as a basic process engineering operation is of paramount importance in the process industry. It is used for the production and purification of solids in numerous chemical, pharmaceutical and food industry processes. The use of mixing technology adapted to the process is the key to achieving the desired product properties.

Crystallization of a solution can be initiated by changing temperature or solute concentration. This can generally be triggered by cooling or evaporating the solvent, but also by adding an antisolvent or adding a new component as in precipitation or reaction crystallization. The process variants as well as the apparatus-based process solutions are strongly dependent on the properties of the material system and are correspondingly diverse.

For successful crystallization, the most suitable process and thus the method for exceeding the solubility, i.e. generating a supersaturation must be determined. A helpful tool for process selection is the solubility curve, which shows the concentration of the dissolved solid over the temperature. Depending on the influence of temperature on the solute concentration, cooling or evaporation is chosen for crystallization, or a combination of both by applying a vacuum.

Crystallization can be initiated by shear, by foreign substances such as impurities, but also by the vessel wall or internals, or by the introduction of seed crystals. If the degree of supersaturation is too high, nucleation clearly dominates crystal growth, and the process becomes uncontrollable. This effect can lead to a broad particle size distribution with an excessive fines content at the same time.

Depending on the material system, further significant parameters such as nucleation and crystal growth kinetics, maximum local energy input or the option of seeding the crystallization need to be elucidated, which are usually determined by experiments on a geometrically similar test scale.

Thus, an important aspect of process control is supersaturation control. By setting the operating point in the metastable region close to the solubility curve, crystal growth is promoted over primary nucleation.

The determination of solubility and metastable range is an elementary investigation in the process development of a crystallization process. These values can be determined in the laboratory by repeated heating and cooling at different substance concentrations.

The picture shows a test stand on a 3-liter scale. Compared to smaller set-ups, this equipment allows not only variation of pressure and temperature and their rates, but also variation of container geometry, stirrer geometry and speed and thus an extended investigation of the target variables product purity, yield or crystal size distribution.

In addition, already on this small scale various inline probes like FBRM or Infrared Spectrometry can be used as powerful tools to clarify the significant process parameters which in later project phases will become decisive for a successful scale-up of the process solution.

*3-liter-scale test stand in R&D Center*

## Mixing requirements

Solids are formed during crystallization, which must be considered when designing agitators. The basic mixing task of suspending is therefore of great importance as a critical success factor for every crystallization process. Furthermore, a good homogeneity in the entire filling volume is required to ensure, for example, uniform growth conditions for the crystals in the entire liquid volume. Depending on the type of crystallization mechanism, heat transfer and renewal of the liquid surface are also relevant.

In addition to these tasks, which are easy to describe in terms of mixing technology, there are other effects such as crust formation or deposits. These can usually be influenced by the agitator design in combination with the mode of crystallization as well.

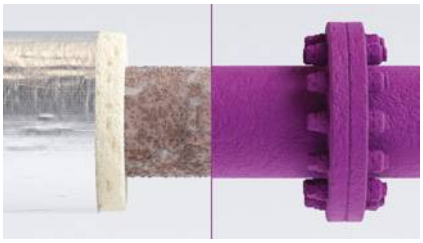
## EKATO solutions for crystallization processes

EKATO can support customers already during the development phase. This starts with basic laboratory investigations on basic parameters, selecting the mode of crystallization and finding the right strategy for a robust process. Taking this as a basis, EKATO is in the position to deliver a complete solution starting from a first estimation until detail engineering, manufacturing and operation. EKATO has excellent experience in designing not only the agitators, but also can assist with expertise in vessel design and process know-how. Furthermore, we can support with CFD simulations and trials in our laboratory or on site.

**For more insights in EKATO R&D capabilities:**
https://youtu.be/p1ZCk9UyGO8

**More Information under:**
https://www.ekato.com/solutions/processes/crystallization/

**For details visit adlinks.chemengonline.com/84645-08**



Evonik Industries

Crosslinking (DAX) technology for improved performance over other options. Polydure coatings protect against abrasion and corrosion, and are durable for many years, the company says. — *AkzoNobel N.V., Amsterdam, the Netherlands*
**www.akzonobel.com**

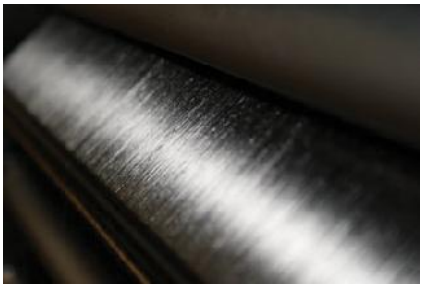
## This compound makes insulation coatings efficient

TEGO Therm (photo) is a new line of tailor-made feedstocks that substantially improve the performance of thermal insulation coatings (TICs). The new product range includes two microporous silica-based granules, TEGO Therm HPG 4000 and TEGO Therm HPG 6806, as well as a heat-resistant, silicone-based binder, TEGO Therm L 300.The three new products from this company's Coating Additives business line are characterized by excellent insulation properties and heat resistance, even at temperatures of up to 250°C. Insulation coatings based on TEGO Therm products substantially reduce energy loss, and they also aid occupational health and safety, because they can significantly reduce the temperature of hot surfaces (safe touch). Insulation coatings also provide protection against moisture penetration and therefore corrosion under insulation (CUI). This significantly increases the service lives of coated items. One target application for this new generation of feedstocks is the technical insulation of pipelines, tanks or various other components in industrial plants. — *Evonik Industries AG, Essen, Germany*
**www.evonik.com**

Xenia Materials

## A new range of supertough carbon-fiber composites

Xecarb ST (photo) is a new family of supertough carbon-fiber composites custom-engineered to close a performance gap in the market and provide superior impact-strength performance. Xecarb ST builds on the proven mechanical strengths of this company's Xecarb range, but shows significantly higher notched impact resistance, low-temperature ductility and tensile elongation at break. With slightly lower density, the new carbon-fiber-composite technology offers these unmatched advantages together with further lightweighting possibilities. Xecarb ST thermoplastic composites are based on selected polyamide matrix materials — PA66, PA6, PA11, PA12, PA6.10, PA6.12 and PA4.10 — addressing different mechanical, thermal and physical requirements. — *Xenia Materials Srl, Mussolente (Vicenza), Italy*
**www.xeniamaterials.com**



Solvay

## A low-temperature prepreg for fast tooling

LTM 350 (photo) is a next-generation carbon-fiber-epoxy, prepreg-tooling material designed to deliver significant time and cost savings for the industrial, aerospace, automotive and race car markets. The carbon-fiber epoxy tooling material offers an industry leading, fast, low-temperature cure cycle (3 h at 60°C) and can also be cured at temperatures as low as 45°C with an extended post-cure. Tools built from LTM 350 can be continuously cycled at temperatures up to 150°C, delivering highly accurate composite parts. As a low-temperature prepreg with user-friendly tack, drape and handling, LTM 350 was designed to enable the shortest possible lay-up times while providing the highest-quality surface finish. — *Solvay S.A., Brussels, Belgium*
**www.solvay.com**

## Industry's first food-grade hydraulic fluid

Bio-Food Grade Hydraulic Fluids (photo) is said to be industry's only environmentally friendly food-grade hydraulic fluids. With oxidation performance comparable to full synthetics, this is one of the safest hydraulic fluids for the environment and the only one that is food-grade, the company says. Bio-Food Grade Hydraulic Fluids are multi-functional, biosynthetic lubricants that contain ingredients that are classified Generally Regarded as Safe (GRAS), making them ideal for applications with incidental food contact in and around food-processing equipment areas. They may be used on food-processing equipment as a protective anti-rust film, as a release agent on gaskets or seals of tank closures, and as a lubricant for machine parts and equipment in locations in which there is a potential exposure of the lubricated part to food. — *Renewable Lubricants, Inc., Hartville, Ohio*
**www.renewablelube.com** ■

*Gerald Ondrey*

Renewable Lubricants

# New Products

## World's first 5G smartphone for hazardous areas

The IS540.1 (photo) is said to be the world's first 5G smartphone for ATEX and IECEx zone 1/21. The intrinsically safe mobile device, which was also developed for use in 5G campus networks, offers extensive deployment scenarios ranging from predictive maintenance, augmented reality (AR) applications, control and cooperation of production robots and production lines, management of automated guided vehicles (AGVs), autonomous transport robots, remote monitoring and support to PTT video calls in the system area to prevent plant failures. The high-performance Qualcomm QCM6490 chipset, a large 6-in. display, 48-MP main camera, and standards such as Wi-Fi 6, Bluetooth 5.2 and NFC complete the Android 12 smartphone's extensive feature package. — *i.safe Mobile GmbH, Lauda-Koenigshofen, Germany*

**www.isafe-mobile.com**

## These radar level transmitters are Bluetooth enabled

The Rosemount 3408 level transmitter (photo) is a non-contacting radar device designed to optimize ease-of-use, leading to increased safety and enhanced plant performance. While the benefits of radar level measurement are widely acknowledged, the company says radars are still sometimes perceived as being complex to commission, operate and maintain. Addressing this concern, the device provides a range of functions that reduce complexity throughout its lifecycle, including a highly intuitive interface, Bluetooth wireless technology remote capabilities, predictive alerts, in-situ verification, data historian and an upgradeable design. The user interface provides clear pictorial instructions, allowing operators to be easily guided through installation, commissioning, proof-testing, operation and maintenance. This increased ease-of-use gives process and manufacturing organizations the confidence to replace time-consuming manual procedures, thereby helping to increase safety and maximize productivity. — *Emerson, St. Louis, Mo.*

**www.emerson.com**

## Five new laboratory sensors added to this portfolio

There are five new laboratory sensors (photo) that are compatible with this company's Liquiline CML18 handheld laboratory analysis device. The Memosens CPL53E (digital pH sensor), CPL57E (digital pH sensor for low-conductivity water), CPL59E (pH sensor built for harsh conditions), COL37E (optical oxygen sensor) and CLL47E (four-electrode digital conductivity sensor) liquid analytical sensors now join the CPL51E to provide reliable measurement, easy operation and enhanced good laboratory practice (GLP). The new sensors support data and quality management in the verification processes of online measurements, provide immediate and tamper-proof calibration history traceability, with easy data transfer using Bluetooth technology. Using the bayonet connector, the handheld CML18 and Memosens sensors are plug-and-play devices, with support for easily switching output parameters — such as pH, dissolved oxygen and conductivity — at the measuring point. Users can begin making measurements without initial calibration since instruments are pre-calibrated at the factory. — *Endress+Hauser, Greenwood, Ind.*

**www.us.endress.com**

## A new weigh station for batching ingredients

This company's new batch-weighing system (photo) is designed for accurate batching direct to blenders or mixers. The station features a P100 batch-weigh receiver combined with a KT20 loss-in-weight twin-screw feeder, mounted on a collection hopper. The batch-weigh receiver combines a vacuum receiver with a reliable weighing system for batching of major ingredients. The resulting combination allows ingredients to be conveyed and weighed so that accurate batching of ingredients can take place on either a cumulative or sequential basis. The KT20 loss-in-weight twin-screw feeder can accurately add smaller amounts of high-value minor ingredients to the batch. Batch-weigh receivers are available in sizes from 30 to 1,000 L. — *Coperion K-Tron, Salina, Kan.*

**www.coperion.com**

*i.safe Mobile*

*Emerson*

*Endress+Hauser*

*Coperion K-Tron*

Pepperl+Fuchs

Kason

Hans Turck

Dwyer Instruments

Innovative Sensor Technology

## Switch amplifiers for intrinsically safe applications

The new KFU8-SR-EX* (photo) is a universal powered switch amplifier that can be used in intrinsically safe applications and functional safety installations up to safety integrity level (SIL) 2. The new KFU8 device can be supplied with 19 to 30 V d.c. or 90 to 253 V a.c. With this functionality, a single device can be used with various supply voltages. As a result, fewer components need to be kept in stock and in the field technician's toolbox. The switch amplifiers transmit discrete signals from NAMUR sensors or mechanical contacts in the hazardous area to the safe area. A proximity sensor or switch controls the load on the control side via a changeover relay contact. All modules feature line fault detection. In the event of a fault, the relays de-energize and the fault is indicated by LEDs. — *Pepperl+Fuchs, Inc., Twinsburg, Ohio*
**www.pepperl-fuchs.com**

## This centrifugal sifter addresses labor-shortage costs

The Centri-Sifter M1 (photo) is a centrifugal sifter specially designed to help address the high costs associated with maintenance and recruiting, training and retaining skilled labor. The Centri-Sifter M1 sifts, scalps, de-agglomerates and dewaters granular materials ranging from dry bulk solids to solids-laden slurries. Centri-Sifter M1 is said to be the only centrifugal sifter on the market engineered for one-person operation and maintenance, which can help reduce the high cost of skilled labor. The Centri-Sifter M1 features a capacity of up to 15,000 lb/h of dry material and up to 50 lb/h of wet. — *Kason Corp., Millburn, N.J.*
**www.kason.com**

## Programmable, multicolor LED indicators

This company is expanding its portfolio of light-emitting diode (LED) lights with the robust LED indicators of the K100 series (photo). The 100-mm beacons — developed by partner company Banner Engineering — are available in two configurations. The Pro Daylight Visible beacon model offers 12 audible options and has a clear lens that avoids false indications, even in sunlight. It offers bright indication in both indoor and outdoor environments. It features three color options (green, yellow and red) for status indication, operator guidance and other functions. The K100 Pro Indicator model has a diffused lens that appears white when inactive, thereby preventing false indication. It features 14 color options that can be used for status and indication. Both beacon models can include an optional audible alarm and have an IP66 environmental rating. — *Hans Turck GmbH & Co. KG, Mülheim an der Ruhr, Germany*
**www.turck.com**

## This field-configurable flowmeter has no pipe-run requirements

The new Series PI (photo) is a variable-area flowmeter that utilizes a spring-loaded piston. The fluid flow in the application causes this piston to move along the axis of a precision-tapered shaft, creating a variable orifice in direct proportion to the flowrate. The piston is mechanically linked to a read-out pointer and actuates switches or a transmitter. Straight pipe runs are not required before or after the meter, allowing for installation in areas with minimal space. The three-wire version of the Series PI is equipped with a solid-state relay that can be configured in the field for alarm output. — *Dwyer Instruments, LLC, Michigan City, Ind.*
**www.dwyer-inst.com**

## This humidity sensor is designed for industrial drying

The HYT 939P temperature and humidity sensor (photo) is equipped with a PTFE filter, which makes it well-suited for industrial drying applications. The sensor's compact housing allows for easy positioning within the monitored process, while the filter minimizes the influence of particulate matter and volatile organic compounds on the humidity sensor. The sensor is based on a capacitive-polymer measurement principle with a fast response time, low drift and hysteresis. The sensor remains stable in a high-humidity environment and can sustain condensation conditions. It comes fully calibrated and temperature-compensated. — *Innovative Sensor Technology IST AG, Ebnat-Kappel, Switzerland*
**www.ist-ag.com** ■

*Mary Page Bailey and Gerald Ondrey*

# Fractional Solvent-Free Melt Crystallization

*Department Editor: Scott Jenkins*

Fractional crystallization is a stage-wise separation technique that relies upon the liquid-solid phase change and enables the purification of multi-component mixtures, as long as none of the constituents can act as a solvent to the others. Thanks to the level of selectivity that can be achieved in solid-liquid equilibrium, it is ultimately possible to reach high purities for the selected components. This one-page reference provides basic information on fractional solvent-free melt crystallization.

## Principle of separation

The crystallization process relies on the partial freezing of the initial liquid mixture by gradually decreasing its temperature. The frozen solid phase exhibits a different chemical composition to the remaining residual liquid. This phenomenon is the basic physical principle behind the fractional melt crystallization process.

Crystals are allowed to grow on a cooling surface, which separates the feedstock from the coolant medium, as polycrystalline layers. The heat released by the solidification process is withdrawn through the crystalline layer or from the bulk. The driving force results from the net effect of temperature and concentration gradients across both solid and liquid phases.

In a hypothetical case where crystallization continued indefinitely, purified products could theoretically be recovered in 100% pure forms. In practice, trade-offs required at industrial scale make it impossible to operate under these ideal conditions. Nevertheless, a number of strategies, such as partial melting of the solid fraction (sweating), address these challenges and help reach extremely high purity levels.

## Process steps

In a fractional crystallization process (Figure 1), the main steps are crystallization, draining, sweating and total melting. During the crystallization step, high-purity crystals are formed on the cooling surface, while the impurities are mostly concentrated in the remaining liquid (draining). The sweating phase then enhances the purification process and end-product quality through partial melting of the impurities entrapped within or between crystals. Finally, the remaining crystallized material (final purified product), can be melted to remove it from the column and continue with downstream activities.

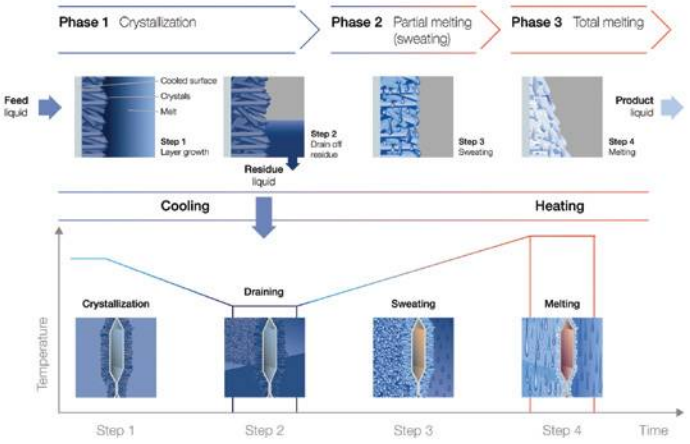



**FIGURE 1.** Fractional crystallization can be used to purify multi-component mixtures and can achieve high purities

## Equipment

Three different technologies and their respective equipment can be used for fractional melt crystallization:

***Falling-film crystallizer.*** In falling-film crystallization, the crystals grow from an agitated melt (falling-film product) inside tubes that are cooled by a co-current cooling medium flow, which runs on the other side of the tubes. In this case, crystals grow on the inside of the tube from the falling film of melt. Reproducible (and high) transfer rates are achieved on both side of the tube. The resulting shear at the crystal-liquid interface transports impurities rapidly into the bulk of the melt.

This technology is robust and easy to operate. In addition, it can handle high throughputs while achieving extremely high purities. More precisely, a typical feed has concentrations between 90 and 99%, and end products can reach 99.99% purity or greater. Glacial acrylic acid, optical-grade bisphenol A and battery-grade ethylene carbonate are purified to their highest grade using this technology.

***Static crystallizer.*** In static crystallization, crystals are grown from a stagnant melt. Versatility and robustness are intrinsic to this technology, which can purify the most challenging products, including those characterized by high viscosities and high or low melting points. Isopulegol, phosphoric acid, wax and paraffins, anthracene/carbazole and satellite-grade hydrazine are chemicals that benefit from static crystallization processes.

***Suspension crystallizer.*** In suspension crystallization, crystals are generated on a cooling surface wall and then scraped off, so they continue to grow in size within a stirred vessel, in suspension (slurry). The solid-liquid separation of the slurry can be performed either by using a wash column or a centrifuge. More complex to operate than the technologies mentioned previously, suspension crystallization has a key advantage of high separation efficiency. In effect, products with purities of 99.5% and above can be achieved in a single crystallization stage, from feedstocks with concentrations of 75–90%. This can drive considerable energy savings. *Para*-xylene and halogenated aromatics are purified using this technology, which can also concentrate aqueous feedstocks, such as food and drink concentrates, or wastewater.

Combining these technologies can enhance their respective features. For example, combining falling-film with suspension and static crystallization is common. ■

**Editor's note**: The content for this column was authored by Sulzer Chemtech (www.sulzer.com).

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# Pilot-Scale Distillation Process Design

The inherent characteristics, requirements and special concerns of pilot- and laboratory-scale distillation columns differ from those of commercial-scale equipment. The scale-related differences of distillation assemblies are presented here

**Glenn Graham and Raymond Rooks**
AVN Corp.

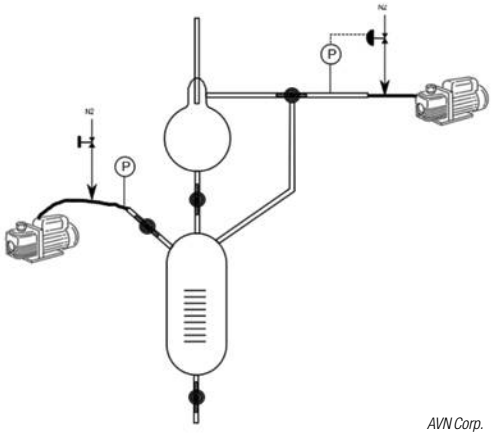
## IN BRIEF

CHALLENGES OF SCALE
HIGH-VACUUM OPERATION
HEAT CONTROL
REFLUX CONTROL
DISTILLATE AND SIDESTREAM PRODUCT TAKEOFF
REBOILERS
CONCLUDING REMARKS

Distillation processes at any scale share many of the same theoretical and practical concepts and concerns. For example, pressure has a similar effect on operating temperature and component vapor-liquid equilibrium. And a specific number of theoretical stages, feed location, feed temperature, reflux ratio, and distillate-to-feed ratio will result in a similar component separation for a given feed composition, column head pressure and differential pressure.

Further, at any scale, vapor and liquid contacting is generally accomplished by trays, random packing or structured packing. Reboilers are usually based on kettle, thermosyphon, or pump-around designs that employ steam, hot oil or electric elements for their heat source to generate vapor. Updraft or downdraft-style condensers are required to condense all or part of the overhead vapor stream. Vacuum or pressure-control systems are required to operate a distillation column below or above atmospheric pressure. Input sensors, pumps and control values are required on most distillation columns.

However, the scale of the equipment has a major influence on its design, construction and operation. Pilot- and laboratory-scale distillation columns have inherent aspects, requirements and concerns that differ from commercial-scale columns. This article highlights the specific concerns imposed on the purpose, design and operation of small-scale distillation equipment, and discusses how these concerns manifest themselves in the actual equipment that is typically used. It also offers unique ideas that have been presented for small-scale equipment. Although this paper is focused on the scale-related differences of distillation columns, many of these concepts apply to other unit operations.




AVN Corp.

**FIGURE 1.** A double-bulb receiver, such as the one shown in the diagram, receives distillate in a small-scale setup

## Challenges of scale

The following list summarizes the main concepts that affect the design of small-scale distillation equipment:

- Certain engineering concepts require a different emphasis or must be implemented in a different manner
- Equipment design, type and availability is different than for commercial-scale
- The main purpose of small-scale systems is usually to collect data, but sample generation is sometimes important
- Facilities in which the distillation equipment is housed must have wide-ranging capabilities to be able to accommodate physical dimension (especially height) requirements, and personal exposure, flammability and reactivity concerns
- The life of the small-scale distillation equipment setup is usually short-term
- Ease of modifying equipment or operation is important

Surface-to-volume ratio is a key engineering concept for certain aspects of small-scale equipment, and is more of a concern than for large-scale equipment. This concern applies to heat loss, column-wall effects related to mass transfer and vacuum leaks.

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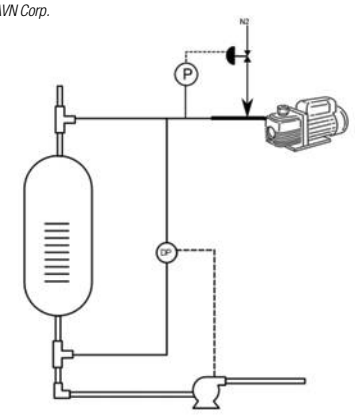
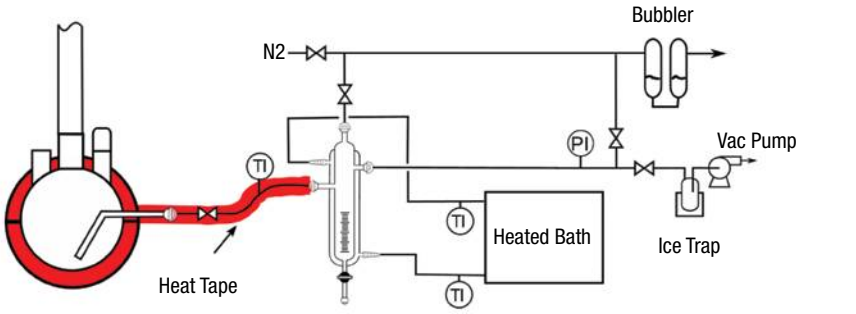



**FIGURE 2.** This small-scale system uses a distillate-collection design similar to a commercial-scale unit




AVN Corp.

**FIGURE 3.** The apparatus to sample high-melting-point materials under vacuum is shown here

***Heat loss.*** Heat loss is a critical concern for distillation columns. For columns above ambient temperature, wall condensation occurs; for columns below ambient temperature, wall boiling occurs. Wall condensation and wall boiling are important because they change the liquid-to-vapor ratio of the flows within the column, and because they have an effect similar to changing the reflux ratio (although heat loss causes a continuous variation in the flows and ratios throughout the column). This effect causes the liquid-to-vapor ratio to be different than expected, based on the apparent reflux ratio (measured by the reflux-to-distillate ratio at the top of the column) and results in a separation that is different than intended. In addition, for packed columns, there could be significantly different flows across the column radius.

***Column-wall effects.*** Column-wall effects are more significant in small-scale columns than commercial-scale units due to the enhanced surface-to-volume ratio. This phenomenon can increase the amount of surface area for mass transfer in a packed column, can provide a path for liquid channeling, which decreases the liquid available for vapor-liquid interaction, and can lead to axial dispersion. These effects can cause the resulting separations to be different than expected based on the inherent characteristics of a given packing. This is especially important because the goal of the smaller equipment is often to model a larger column.

***Vacuum leaks.*** Vacuum leaks are a larger problem in small-scale columns, since the sealing-surface-to-column-volume ratio is larger, so there are more opportunities for leaks. Excessive leaks can prevent the desired operating pressure from being achieved, causing light components to be swept from the condenser to the vacuum system, and, in severe cases at high vacuum, significantly increase the vapor flowrate.

Some instrumentation and control devices used for small-scale distillation columns are similar to those used for commercial-scale units, such as pressure, differential pressure and liquid-level instruments. However, flowmeters, valves and pumps must be able to work with low flowrates at a wide range of process conditions. It is often difficult to accurately measure and control low flowrates, and the small-diameter tubing and orifices required can lead to plugging problems.

Packing and trays have minimum column diameters that will allow them to generate representative data that can be used for simulation validation or scaleup. For random packing, the rule-of-thumb is that the column diameter should be at least eight times the packing-piece diameter. In some cases, this ratio can be smaller. For example, with Pro-Pak packing, this ratio is about six. Structured packing has similar constraints based on the packing crimp size. For Oldershaw-style trays, the minimum diameter is about 19 mm. Below this diameter, the hole pattern on the tray deck becomes non-representative, and the small diameter of the downcomer causes problems with vapor-liquid disengagement. Also, the liquid flow suffers from surface tension effects.

For small seals and joints, the choices are often limited to those that are the correct size and can accommodate the pressure, temperature and chemical compatibility requirement for both glass and metal.

The purpose of small-scale distillation columns is usually for the collection of simulation-validation or scaleup data. Additional instrumentation is often required, such as an enhanced number of column thermocouples, for control or to observe the column temperature profile. More sample points may be required, and sampling frequency is normally higher than for a commercial operation. Often, it is important to use glass distillation columns so that tray activity, process fluid color, foaming issues or fouling problems can be observed.

The following sections will provide details about equipment and tools that are used to address many of the concerns discussed above.

## High-vacuum operation

For distillation under vacuum, differences between small- and large-scale distillation units include methods of sample collection.

***Distillate and sidestream recovery.*** The traditional means of collecting distillate from a small-scale

**FIGURE 4.** The photo shows a glass feed section with vacuum jacket and silvering. (Courtesy of Surplus Components, Granite Falls, Minn.)

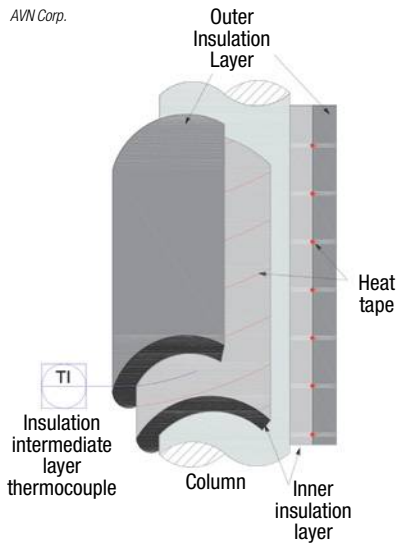



**FIGURE 5.** The diagram shows an unjacketed distillation column with insulation and heat tape. (Copyright R. Nunley, Matric. Used with permission)

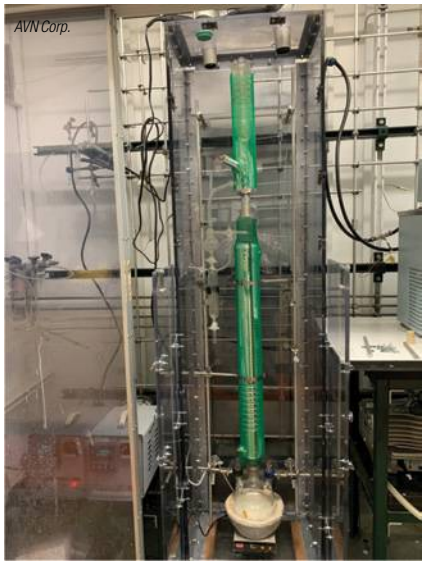



**FIGURE 6.** The batch distillation column in the photo is surrounded by a homemade Plexiglass enclosure with heat guns

distillation column is using a glass double-bulb receiver (Figure 1). During normal operation, a vacuum pump maintains the column and both bulbs of the receiver at the same pressure. Condensate flows continuously and by gravity into the upper bulb, then down to the lower bulb. When the lower bulb has become sufficiently filled, it will be isolated by valves so that condensate continues to flow into the upper bulb. The vacuum on the lower bulb will be released, which allows its contents to be drained. The lower bulb is then re-evacuated to the same pressure as the column and the upper bulb and the valve between the bulbs is opened to allow condensate to once again flow from the upper to the lower bulb.

This system for distillate collection works well for many small-scale vacuum-distillate columns. The equipment requirements are minimal, and it is easy and fast to assemble. However, it is prone to column pressure "bumping" if the lower bulb re-evacuation is not done properly, and this design does not allow for unattended operation.

As an alternative, for some small-scale distillation columns, a system for distillate collection is utilized that is typical of that used for commercial scale (Figure 2). Condensate flows into a surge vessel, which has a liquid-level instrument that controls a pump. The pump flowrate is adjusted, based on the liquid-level instrument, to maintain a flowrate that is equal to the condensate rate. The pump also pumps from vacuum to atmospheric pressure. This system allows for automated operation and avoids upsetting the column pressure. However, it requires additional equipment, and there may be pump-priming issues.

These two methods can also be used for the collection of sidestreams. However, care must be taken with regard to the vent system. The pressure at the sidestream will be higher than at the top of the column due to the pressure drop in the trays or packing, so the sidestream liquid-takeoff point on the column must be vented to the column at that location. A nitrogen blowback system may also be required to avoid the escape of vapors from the column. This involves feeding nitrogen into the instrument line at a superficial velocity that is sufficient to prevent the flow of condensable vapors from entering this line from the column in order to prevent measurement errors.

***Sample collection from the kettle.*** Small-diameter continuous distillation columns will normally require a pump to remove the tails stream from the reboiler, which is often a round-bottomed flask with a heating mantle. Ideally, the height to which the liquid must be lifted is minimized and the line diameter is large enough so that pressure drop is negligible, since the liquid is at its bubble point and may flash in the pump inlet line. This concern becomes even more important if the column is under vacuum.

If the column is operated in batch or semi-batch mode, a continuous tails-removal system is not required. However, there may be the desire to collect periodic reboiler samples. One way to accomplish this is with a receiver that is connected to a vacuum pump. If the melting point is above ambient temperature, then heat tape or heat jackets will likely be required. Figure 3 shows an example of a vacuum-sampling system for a reboiler in which the contents have an elevated melting point.

In a later section, other sampling topics are discussed, including sampling from column packing or trays, and the collection of low-flowrate condensate streams.

## Heat control

Heat loss or gain in a distillation column is a major concern, since it affects both the liquid-to-vapor ratio and the flowrates. Therefore, it impacts the separation and column capacity. This issue requires more attention for small-scale distillation columns than for commercial columns due to the much higher surface-to-volume ratio of small-scale columns.

***Vacuum jacket and silver.*** For glass columns, a common type of insulation is vacuum jacketing and silvering (Figure 4). The use of a vacuum jacket reduces heat loss from conduction and convection, while silvering reduces heat loss by radiation. Narrow windows located in the front and back of column sections allow for visual inspection of tray activity. Since the temperature of the distillation column wall will normally be higher than the outer wall of the

**FIGURE 7.** This photo shows a commercially available heated encloser for larger systems. (Courtesy of Benko Products, Sheffield Village, Ohio)

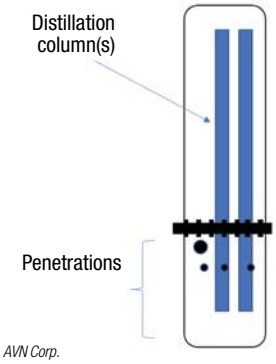



**FIGURE 8.** Vacuum vessels, like the one in the diagram, can be used for low-temperature distillation columns

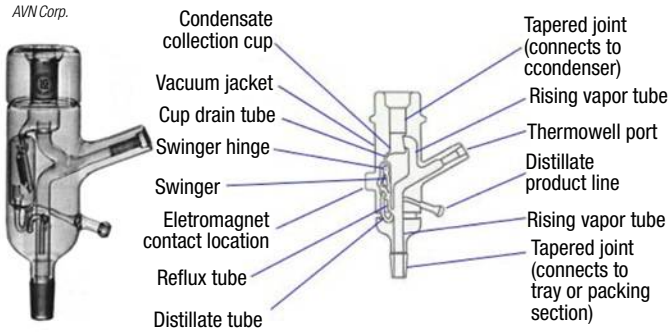



**FIGURE 9.** This liquid dividing head reflux splitter is equipped with a swinging bucket to collect distillate

jacket, glass bellows are incorporated into the column wall to allow the inside tube to expand relative to the outside tube. Bellows can accommodate reasonably high temperature, but can crack if the column temperatures become excessive.

Tapered ground-glass joints are common on glass column sections and the vacuum jacket is often extended to include the tapered joint. However, this design shows much heat loss at the joint, which is the main source of heat loss in column sections. Another concern about tapered joints is that they can become frozen, making it difficult to free the column sections from each other; Teflon sleeves are often used to help prevent this. Vacuum grease is also commonly used, although this can contaminate the process if too much is used. This is a common mistake, and practice is required on applying it correctly. The socketed nature of these joints presents some potential disadvantages: column modifications usually require disassembling the column; vacuum leaks are sometimes hard to fix; and column alignment is more difficult.

Vacuum jacketing allows for rapid assembly of laboratory-scale distillation columns. However, care must be taken in their assembly, mounting and use. These sections are relatively delicate and are prone to breakage. They must be carefully mounted so that uniform pressure is applied by the supporting column clamps, and a sufficient number of clamps must be used to minimize downward force on any of the column sections.

Vacuum-jacketed glass sections have the potential to implode, resulting in glass shards being projected in every direction. To prevent potential injury, these sections must be wrapped in plastic mesh or coated with transparent plastic. More commonly, the glass bellows can develop cracks, allowing the vacuum, and its insulation capability, to be lost. If a vacuum-jacketed column section feels hot during normal operation, this indicates that the vacuum may have been compromised.

For some chemical systems, solids may build up in the trays. If not for the silver coating, the column sections can often be heated in ovens used for glass annealing to burn out the solids. However, this will destroy the silvering and require that it be reapplied by the supplier.

One possible alternative is to have a non-silvered jacket that can be evacuated with a vacuum pump. This allows the column section to be heated to a high temperature in an oven to burn out polymer, where traditional silvering would be destroyed and thermal stresses on a thin-wall vacuum jacket may lead to breakage. To minimize radiant heat losses, reflective nickel foil can be wrapped around the jacket. Traditionally, glass vacuum jackets are made with bellows that allow for the expansion of the hot inner process tube relative to the cold jacket. If bellows are not installed in the jacket for the non-silvered alternative, the maximum operating temperature for the column section will be limited to 150°C or less.

Vacuum-jacketing works well for columns that will not need to get too hot or have too many joints, as well as those columns for which the main purpose is to produce product, usually for sample quantities. A significant amount of heat loss can occur from the joints in hot columns. A rough guideline is that it is not recommended to validate simulation models using vacuum-jacketed columns when the temperature is above 120°C, and the column has more than four joints, not counting the connection to the condenser. In this case, one should consider the solution discussed in the next section.

***Heat tape and insulation.*** Metal columns normally do not have jackets. Glass columns can be purchased without jackets to reduce the cost or to allow the columns to be burned out, as discussed earlier. Otherwise, the amount of heat loss that would occur from a vacuum-jacketed column would be unacceptable due to the high temperature and large number of joints usually present with a tall column. In these cases, the use of heat tape and insulation is a technique that allows a small-scale distillate column to operate at near-adiabatic conditions [*1*].

This technique can be used for unjacketed glass and metal columns. It involves wrapping each column section with two layers of insulation and wrapping heat tape between the insulation layers. A thermocouple should be inserted near one of the heat tapes and another thermocouple should be located within the column to measure the process temperature. If the process temperature is not available, a thermocouple can be placed on the outer wall of

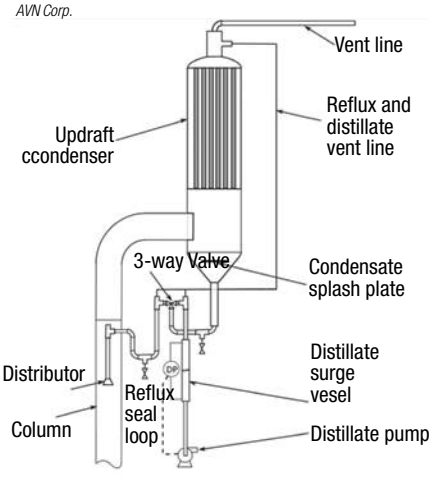



**FIGURE 10.** The reflux splitter shown here has a three-way valve to divert the distillate

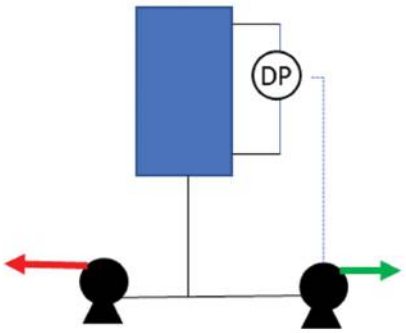



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**FIGURE 11.** Calibrated metering pumps can be used in reflux splitters to control the reflux ratio

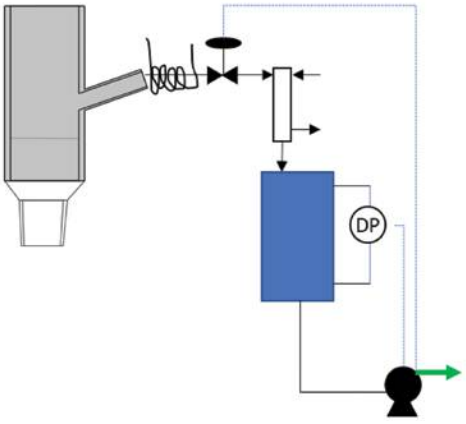


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**FIGURE 12.** The diagram shows how to remove vapor from a sidestream with a control valve

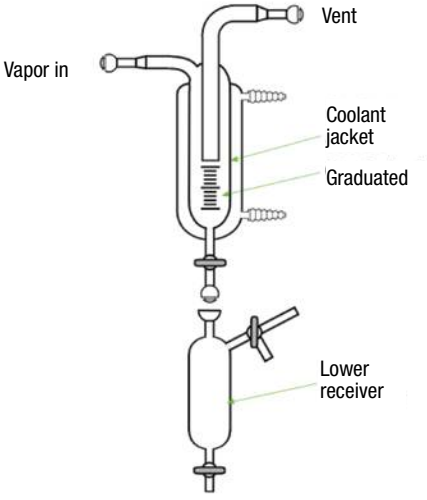


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**FIGURE 13.** A condenser-receiver, like the one shown here, can be used for low-flowrate condensate

the column. During operation, the heat input from the heat tapes is adjusted so that the two thermocouples read the same temperature, indicating that there is no heat flow into or out of the column. Figure 5 shows a conceptual diagram of this technique.

For columns with significant temperature profiles, multiple zones are required. Each zone will represent one or more heat-tape sections, and each of these sections will operate at a different temperature. The goal is that the temperature of each heat-tape zone is equal to the average process temperature within that zone.

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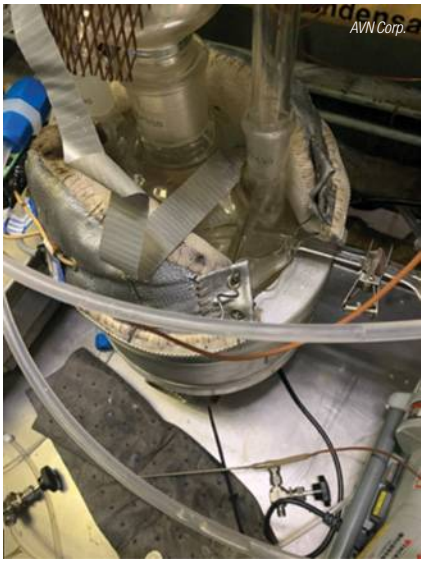


**FIGURE 14.** The round-bottomed flask is used as a reboiler, with a heating mantle

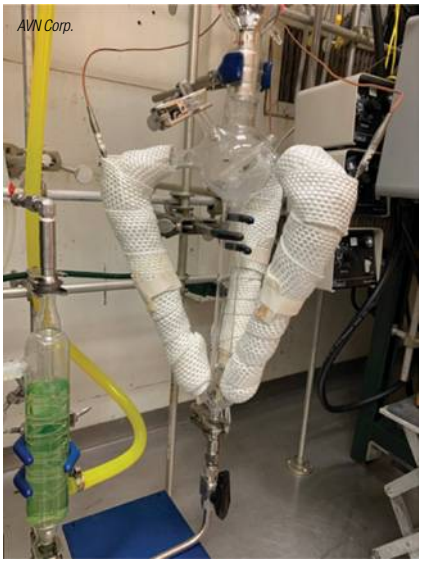


**FIGURE 15.** This thermosyphon reboiler has three arms wrapped in heat tape

Any given point in a column section may not be exactly adiabatic, but the average of the heat loss and gain for that zone will be near zero.

In addition to the extra effort to wrap the column sections with heat tape and insulation, the process control system for this type of a setup is more complex due to the need for thermocouples and heat-tape controllers, as well as the required configuration of the control system and the connection of the control system to the heat tapes.

***Heated enclosure.*** Another means of minimizing heat loss is to operate the distillation column inside a heated enclosure. By reducing the temperature difference between the process within the column and the external ambient temperature, glass vacuum-jacketed column sections may now be acceptable, whereas they may have experienced too much heat loss at the original room temperature.

One of the main advantages of using a heated enclosure is for chemical systems with high melting points. However, it is usually difficult to heat tape or trace all the process lines in a way that avoid all cold spots. Also, during column startup, the vapors initially rising in the column are exposed to cold surfaces, which can cause freezing to occur within the column.

Figure 6 shows a "homemade" Plexiglass enclosure for a 1-in. diameter glass distillation column, heated by two heat guns, with the capability to operate at temperatures up to 60°C. Figure 7 shows an example of a larger, commercially available enclosure.

If the column is manually operated in a heated enclosure, the upper temperature limit is determined by human limitations. Also, any instruments within the enclosure must be able to operate at elevated temperatures. Feed tanks and receivers may need to be located near the column, so this needs to be accounted for regarding the size of the enclosure.

***Vacuum vessel.*** For distillation columns operating below ambient temperature, a vacuum vessel can be used (Figure 8). For this system, the distillation column and associated piping and instrumentation are located inside of a vessel that can be evacuated by use of a vacuum pump. This eliminates heat gain by convection and conduction, and radiation effects are normally negligible at these conditions. If that is not sufficient, it is also possible to line the vessel with multi-layer insulation. This is the approach used in some small cryogenic nitrogen plants.

The main difficulties with this system have to do with the assembly and mounting of the column within the enclosure, sealing of the piping and instrument line penetrations, the necessity of complete automation of the column, and sealing of the vessel shell. In Figure 8, all the penetrations are below the vessel flange, so it can be removed to work on the equipment.

This approach can also be used with distillation columns operating at very high temperature or with compounds with high melting points, in which heat taping or tracing may not be practical. In this situation, prevention of heat loss by radiation may also be required.

## Reflux control

Several approaches are available for controlling the reflux ratio in smaller-scale distillation units, as discussed in this section.

***Liquid dividing head.*** The typical way to control the reflux ratio for small laboratory columns is by using a liquid dividing head. Numerous designs for this device exist, and the main principle of operation is that all of the condensate is directed to the reflux return or to the distillate-producing line for a specific period of time (usually in the range of 2 to 3 seconds for the minimum time period). Therefore, the reflux ratio is determined by the ratio of time, rather than by the ratio of flowrates, as for a commercial column.

Figure 9 shows a liquid dividing head with a swinging bucket. This device would be located between the top of the column and an updraft condenser. The condensate drains into the swinging bucket, whose movement is controlled by an electromagnet connected to a timer. When the electromagnet is turned on, the swinging bucket is pulled into the distillate position, in which the condensate is directed to the distillate line. When the electromagnet is off (reflux position), the condensate is allowed to drain to the top of the column.

These devices are relatively simple, with the only moving part being the swinging bucket. No pumps or flowmeters are required, which is very beneficial at the low flowrates

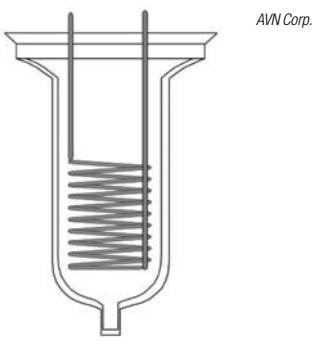


**FIGURE 16.** In a kettle reboiler with a heating coil, hot oil or steam flows through the coil

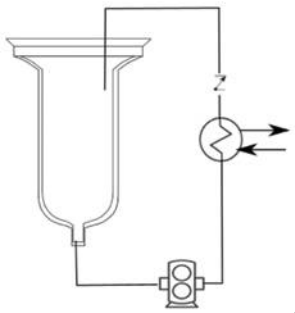

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**FIGURE 17.** A forced-circulation reboiler, like the one shown here, has the best heat transfer, but is the most complex

characteristic of laboratory and small pilot columns. Highly accurate reflux ratios, down to a value of about 0.5, can be achieved if the swinging bucket moves quickly and is controlled by a precise timer.

It is important that the magnet be mounted next to the liquid dividing head so that the swinging bucket is pulled straight out and not to one side of the other, which can bind the hinge or slow the movement. For reflux ratios of 1.0 and greater, the off-time (distillate) should be set at 2–3 seconds. Less than this amount of time introduces error from the switching time. More than this amount of time allows the top tray, or top of the packing, to begin to dry out. Reflux ratios below 0.5 will also tend to dry out the top of the column. In addition, this requires an electromagnet that will not overheat when energized for most of a reflux cycle. To resolve this problem, it is possible to purchase reverse liquid dividing heads, in which the distillate position corresponds to the electromagnet being de-energized. Some electromagnets have been built with cooling capability.

Another concern is polymerizable chemicals. Vapor can condense, uninhibited, on the swinging bucket hinge, polymerize, then cause the hinge to seize. In general, it is good practice to check on a regular basis that the swinging bucket is operating properly.

***Three-way valve.*** For metal columns or larger glass columns, liquid dividing heads are less practical, and are difficult to obtain. An alternative technique, which operates according to the same principle as the liquid dividing head, is based on a three-way valve that can be actuated by a solenoid (Figure 10). As with the liquid dividing head, the reflux ratio is controlled by a timer, which, in this case, is connected to the three-way valve. Either an updraft condenser, as shown in the figure, or a downdraft condenser, can be used. It is important to balance the pressure on each side of the three-way valve so that the condensate flows at the same rate in both the reflux and distillate positions.

***Reflux pumps.*** For a system similar to what would be implemented in a commercial-scale column, it is also possible to use calibrated metering pumps, shown schematically in Figure 11, or a pump with control valves and flowmeters to control the reflux ratio. A surge vessel with a liquid-level instrument is also required. This is usually used to control the distillate rate. The reflux rate would be controlled at a fixed flowrate.

This system allows for a wide range of reflux ratios and works well with automated distillation columns. The possibility of a pressure bump, described earlier, is greatly reduced with this system. However, it is more expensive and requires additional effort to set up.

***Fixed reflux ratio.*** In some cases, the operating temperature of the column may be very high, making it expensive and difficult to use the equipment discussed previously. In addition, the pressure may be high, complicating the situation even more. If the reflux ratio can be fixed at a specific value, one possible solution is to design a liquid distributor in which the condensate is split at a constant ratio, into the reflux and distillate. This requires no moving parts or seals, and would be relatively inexpensive. The main concern would be verifying that the distributor splits the flow as expected, usually with water tests, similar to what is used in large-scale distillation columns.

## Product takeoff

Removing sidestream products is often an important aspect of smaller-scale distillation columns. Several considerations are discussed here.

***Liquid sidestream.*** The liquid dividing heads described above can also be used for liquid sidestreams. The concepts are the same as for the collection of distillate, except that the pressure must be balanced between the vapor and liquid for the sidestream make line. Otherwise, either vapor will blow out the sidestream make line or the sidestream liquid will be prevented from flowing.

As an alternative, a special column section can be used that collects liquid in an annular cup. The cup must be connected to a pump that can then continually remove sidestream product from the column.

One advantage to using a liquid dividing head to collect a liquid sidestream is that it provides an indication of the liquid flowrate below the sidestream takeoff point, since the reflux timer controls the ratio of the reflux and sidestream flowrates.

***Vapor sidestream.*** Figure 12 is a schematic diagram for an apparatus to remove a vapor sidestream from a small-scale distillation column. The column section that allows vapor to flow out of the column can be a repurposed feed section or a relatively simple glass piece made for this purpose. The vapor is maintained above the dew point by heat tapes prior to flowing through a control valve. The discharge from the valve flows into a downdraft condenser, and the condensate drops into a surge vessel. A liquid-level instrument then controls a pump connected to the bottom of the surge vessel. The surge vessel must operate at a lower pressure than the column to provide pressure drop across the valve.

An alternative design is to use a flooded condenser that doubles as a surge vessel. If the pump rate is slow, the vapor will flow into the condenser, and the condensate will gradually fill the condenser, cover the cooling surface, and slow or stop the condensation and vapor flow. When the pump rate is increased, the liquid level will decrease and expose more surface for condensation.

***Low-flowrate vent condenser.*** For some laboratory columns, the main condenser may be a partial condenser, in which case the vent stream contains a small amount of condensable material. Figure 13 shows an apparatus that can be used to condense and collect this material from the vent stream, and accurately determine the flowrate, even if the rate is as low as 4–5 mL/h.

The device consists of a jacketed vessel for coolant. A large-diameter

dip-tube extends halfway down the vessel. This ensures that the vapors entering from the top of the vessel contacts the cooling surface but leaves adequate volume in the bottom for the condensate.

For operation at atmospheric pressure, the condenser-collection vessel can be simply drained. If the column is operated under vacuum, a lower receiver, which can be evacuated by a vacuum pump, is connected to the bottom of the upper vessel, as shown in Figure 13.

## Reboilers

The following describe different types of reboilers for small-scale distillation units.

***Round-bottomed flask with heating mantle.*** The round-bottomed flask is the typical reboiler used for laboratory-scale 1-in.- and 2-in.-diameter columns. Figure 14 shows an example. They are simple, easy to install and work well for batch distillation columns, but can also be used for continuous columns with the addition of a port for liquid take-off (for tails).

However, the low surface-to-volume ratio prevents the use of glass round-bottomed flask reboilers for most larger columns due to the lack of sufficient heat-transfer surface area. In addition, the reboiler residence time may be too long, especially for larger flasks, and promote decomposition of materials for some chemical systems.

For high heat input, the temperature difference across the flask heating surface can become too high for the integrity of the glass. Boiling chips are routinely used, due to lack of agitation, which work reasonably well, but bumping is possible, especially under high vacuum. However, an agitator can be added if an appropriate joint is created to offset the column connection, although this adds additional opportunity for vacuum leaks and agitators tend to be expensive.

***Thermosiphon.*** For continuous columns, the thermosiphon reboiler provides an improved surface-to-volume ratio. It has no moving parts but relies on natural convection. They typically have two or three arms that are wrapped in heat tape, or possibly jacketed for hot oil. Figure 15 shows an example of a thermosiphon reboiler with three arms.

These reboilers have reduced residence times and avoid hot spots on the heating surface. However, the liquid level must be maintained within a relatively narrow range, which requires more attention during operation. Also, they are not appropriate for batch distillations, due to the low holdup, and they do not work well for high-vacuum operation because of static liquid pressure on the boiling point along the heating arms.

***Kettle reboiler with heating coil.*** This style reboiler is a further enhancement with regard to heating surface area. The design is relatively simple and usually has a metal coil located toward the bottom of the kettle, shown schematically in Figure 16, through which hot oil (or steam) flows. An electric immersion heater could also be used. Often, this style reboiler will have an agitator.

The heat transfer for the coils is very good, with a low temperature difference between the coil and process. The temperature of the hot oil at the coil inlet is set at a specific value, which then becomes the maximum for the heating coil, so decomposition is minimized. This type of reboiler also works well for batch distillation if the heating coils are low enough in the kettle.

However, a hot-oil system with cooling capability is required (unless electric immersion heaters are used). The process chemicals must be compatible with the metal coil. And the coil must be sealed well where it passes through the headplate.

***Forced-circulation reboiler***. In terms of heat transfer and operating conditions, probably the ultimate system is the forced-circulation reboiler (Figure 17). However, it is also the most complex. It consists of a vessel for vapor-liquid disengagement, a circulation pump and heat exchanger. Typically, the liquid is pumped at a relatively high rate through the heat exchanger and is restricted from vaporizing until entering the top of the vessel. This minimizes the formation of deposits on the heat-transfer surface.

The heat exchanger size can be arbitrarily selected to suit the heat-duty requirements, and can, therefore, provide higher heat inputs than any of the other reboiler styles discussed earlier. The reboiler can be designed to minimize liquid holdup in the vessel. These systems work well in high-vacuum applications and can be used for batch distillation columns.

Since a pump, heat exchanger and interconnecting piping are required, the process chemicals must be compatible with the materials of construction. The pump and its seals must be suitable for the reboiler operating conditions. A hot-oil system or steam must be available. The equipment cost and setup time are higher than for the other types of reboilers discussed.

## Concluding remarks

As compared with commercial distillation columns, the design and operation of laboratory- and pilot-scale columns are greatly influenced by their purpose, the effect of scale on engineering principles, the availability of equipment, and the short-term nature of projects. ■

*Edited by Scott Jenkins*

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# Boiler Water Essentials: Water Is Water (Not)

When it comes to water used in boilers, it is important to remove potentially problematic impurities. This offers a potentially huge return on investment, even with the prevention of just one major upset, let alone recurring failures

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## IN BRIEF

IT STARTS WITH MAKEUP

INFLUENCE OF CONDENSATE IMPURITIES

BOILER-WATER TREATMENT

A FINAL NOTE

Several decades ago, a popular TV commercial showed a cantankerous man driving down a two-lane road. The vehicle's tailpipe was spewing smoke and nearly blinding the drivers behind. One of his passengers suggested he consider changing his brand of motor oil, to which the man growled, "Motor oil is motor oil." The announcer went on to say that "Motor oil definitely is not motor oil," followed by a pitch for a particular product.

Unfortunately, suggesting that poor water quality may cause problems in plant boilers can yield a similar response from plant personnel: "water is water." Nothing could be further from the truth.

This article provides straightforward arguments against the "water is water" philosophy that appears much too often at industrial plants. Increased emphasis on improved water-system operation and staff training offers a potentially huge return on investment, even with the prevention of just one major upset, let alone recurring failures.

### It starts with makeup

As a basis for discussion, we will use Figure 1, which shows a representative diagram of an industrial steam-generating system.

In power-generation boilers, the high temperatures and pressures require high-purity makeup water, with contaminants limited to low part-per-billion (ppb) concentrations. However, lower-pressure industrial drum units can tolerate some impurities, as the milder temperatures reduce the potential for scaling and corrosion. The American Society of Mechanical Engineers (ASME; www.asme.org) recently updated its long-standing industrial boiler-water-chemistry guidelines [*1*]. Table 1 of this article is an extract from Table 1 of these guidelines for water-tube drum boilers with superheaters, and is

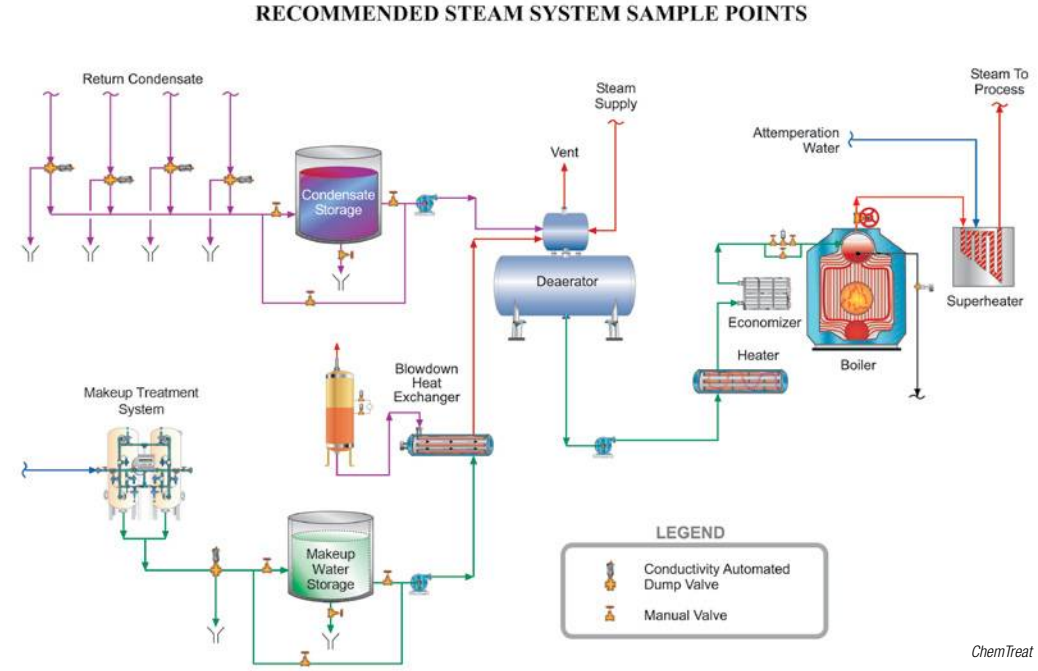



**FIGURE 1.** Common schematic of an industrial steam generating system. The blowdown heat exchanger and feedwater heater are auxiliary items that may or may not be present

representative of the steam generator type shown in Figure 1. We will refer to these data several times in the following discussion.

Even in low-pressure steam generators, impurity ingress control is important. Observe the low limits for feedwater hardness. For decades, a popular method of makeup-water hardness removal has been sodium softening by ion exchange. However, the authors and colleagues have seen numerous instances of hardness excursions caused by inadequate softener operation and maintenance. Even more alarming are cases where operators were directed to bypass the system and feed raw water directly to the boilers when the softener malfunctioned. The typical result of hardness excursions is shown in Figure 2.

Calcium carbonate ($CaCO_3$) is the most common scale, but other deposits are possible, including calcium sulfate and magnesium and calcium silicates. All deposits are strong thermal insulators and can cause tube overheating and failure (Figure 3).

Calcium carbonate forms from the inverse solubility with temperature of dissolved calcium and bicarbonate alkalinity ($HCO_3^-$).

$$Ca^{2+} + 2HCO_3^- + \text{heat} \rightarrow CaCO_3\downarrow + CO_2\uparrow + H_2O \quad (1)$$

As added protection against this scaling mechanism, some plant makeup systems include an ion-exchange dealkalizer or split-stream dealkalizer or downstream forced-draft decarbonator. With acid feed ahead of the decarbonator, most alkalinity converts to carbon dioxide, which then vents from the unit.

$$H^+ + HCO_3^- \rightarrow CO_2\uparrow + H_2O \quad (2)$$

It is not unheard of to simultaneously see poor performance from both the softener and the decarbonator, which greatly increases the potential for $CaCO_3$ scale formation in the boilers.

Another benefit of makeup dealkalization is that alkalinity, upon reaching the boiler, is in large measure converted to $CO_2$ via the following reactions:

$$2HCO_3^- + \text{heat} \rightarrow CO_3^{2-} + CO_2\uparrow + H_2O \quad (3)$$

$$CO_3^{2-} + \text{heat} \rightarrow CO_2\uparrow + OH^- \quad (4)$$

Carbon dioxide flashes off with steam and can increase the acidity of the heat exchanger condensate and condensate-return piping when the $CO_2$ redissolves.

$$CO_2 + H_2O \leftrightarrows H_2CO_3 \leftrightarrows H^+ + HCO_3^- \quad (5)$$

Although the pH generated by Reaction (5) has a relatively mild lower limit, the acidity is more than enough to cause significant carbon-steel corrosion in condensate-return systems (Figure 4).

Even with a properly operating softener and decarbonator, many other dissolved ions pass directly to the steam generators. These include chloride, sulfate and silica. While lower-pressure boilers can tolerate some dissolved solids, adherence to the conductivity guidelines shown in Table 1 often requires frequent or steady blowdown, which wastes water and energy. Furthermore, conditions may arise where the ions induce direct corrosion. Some of these mechanisms are explored in the next section.

A makeup-treatment method being adopted at some facilities is reverse osmosis (RO) installation or retrofit. RO lowers the concentration of virtually all dissolved ions. Reliable RO design and operation requires detailed feedwater analyses. A typical design includes upstream particulate filters, or perhaps even micro- or ultrafiltration, to minimize mechanical fouling of RO membranes [*2*].

## Condensate impurities

For many boilers like the type shown in Figure 1, as well as other units, ASME feedwater guidelines are very important. Apart from makeup, feedwater conditions are often significantly influenced by condensate return chemistry. Because of the enormous variety of materials produced at industrial plants, many compounds may potentially enter the condensate return from heat exchanger leaks or other sources. Unfortunately, as with makeup-water-system operation, condensate-return chemistry is frequently neglected until a major upset occurs.

A classic example comes from the power industry, but can easily apply to many heavy-duty industrial boilers, including co-generation units. This power plant's generating fleet included a relatively small, low-pressure (1,250 psig) unit with a condensing steam turbine. The condenser was on once-through cooling from an artificial lake. After a preplanned maintenance outage, plant chemists discovered the feedwater total dissolved solids (TDS) concentration had increased from normally low parts-per-billion levels to values approaching 1 part per million (ppm). The laboratory staff traced the leak back to the condenser and requested an immediate unit shutdown to find and repair the leak. Plant management refused because the utility was selling power (another example of the "water is water" mindset). This condition continued for three weeks. Plant chemists worked diligently to maintain boiler water chemistry as close to normal as possible, but within two to three months, boiler tubes began failing with regularity. Eventually, the entire boiler had to be re-tubed at a cost many times higher than the company made from the power sales. Metallurgical analyses revealed underdeposit corrosion that led to hydrogen damage throughout the boiler (Figure 5).

The equation below represents a well-known reaction that can occur under boiler-tube deposits.

$$MgCl_2 + 2H_2O + \text{heat} \rightarrow Mg(OH)_2\downarrow + 2HCl \quad (6)$$

One product of this reaction is hydrochloric acid (HCl). HCl can definitely cause corrosion on its own,

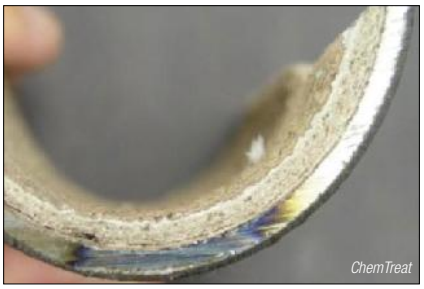



**FIGURE 2.** This layered boiler-tube scale is caused by multiple hardness incursions

**FIGURE 3.** A boiler tube that has bulged and blistered by overheating

| TABLE 1. INDUSTRIAL BOILER WATER CHEMISTRY GUIDELINES* | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| DRUM OPERATING PRESSURE | psig | 0-300 | 301-450 | 451-600 | 601-750 | 751-900 | 901-1000 | 1001-1500 | 1501-2000 |
| **FEEDWATER** | | | | | | | | | |
| D.O. (mg/L) as measured before oxygen scavenger addition | | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 | <0.007 |
| Total iron (mg/L as Fe) | | ≤0.10 | ≤0.05 | ≤0.03 | ≤0.025 | ≤0.02 | ≤0.02 | ≤0.01 | ≤0.01 |
| Total copper (mg/L as Cu) | | ≤0.05 | ≤0.025 | ≤0.02 | ≤0.02 | ≤0.015 | ≤0.01 | ≤0.01 | ≤0.01 |
| Total hardness (mg/L as $CaCO_3$) | | <0.5 | ≤0.3 | ≤0.2 | ≤0.2 | ≤0.1 | ≤0.05 | ≤0.01 | ≤0.01 |
| pH @ 25°C | | 8.810.5 | 8.8-10.5 | 8.8-10.5 | 8.8-10.0 | 8.8-10.0 | 8.8-9.6 | 8.8-9.6 | 8.8-9.6 |
| Nonvolatile TOC (including oily matter) | | <1 | <1 | <0.5 | <0.5 | <0.5 | <0.2 | <0.2 | <0.2 |
| (mg/L as C) | | | | | | | | | |
| **BOILER WATER** | | | | | | | | | |
| Silica (mg/L as $SiO_2$) | | ≤84 | ≤72 | ≤40 | ≤30 | ≤17 | ≤5.9 | ≤1.7 | ≤0.6 |
| Hydroxide alkalinity (mg/L as $CaCO_3$) | | Book has a special note for these parameters | | | | | <10 | <2 | <2 |
| Max total alkalinity (mg/L as $CaCO_3$) | | <210 | <180 | <150 | <120 | Book has special note | | | |
| Max suggested specific conductance | | ≤1,600 | ≤1,400 | ≤1,150 | ≤920 | ≤230 | ≤190 | ≤150 | ≤80 |
| (µS/cm @ 25°C) to comply with steam purity limits | | | | | | | | | |
| **SATURATED STEAM PURITY TARGET** | | | | | | | | | |
| TDS (maximum, mg/L) | | <0.3 | <0.3 | <0.3 | <0.3 | 0.1 | 0.1 | 0.1 | 0.1 |
| Sodium (estimated from TDS, µg/L as Na) | | <100 | <100 | <100 | <100 | <30 | <30 | <30 | <30 |
| **SUPERHEATED STEAM PURITY TARGET** | | | | | | | | | |
| Sodium (µg/L as Na) | | <20 ppb (consult turbine supplier or qualified consultant for appropriate values) | | | | | | | |
| *Note: This is an extract from Table 1 of Ref. 1* | | | | | | | | | |

but the compound can also concentrate under deposits where the reaction of the acid with iron generates atomic hydrogen that penetrates into the metal wall and reacts with carbon atoms in the steel to generate methane ($CH_4$):

$$4H + Fe_3C \rightarrow 3Fe + CH_4\uparrow \quad (7)$$

Gaseous methane formation causes cracking, greatly weakening the steel's strength. Hydrogen damage is very troublesome because it cannot be easily detected. The phenomenon continues to plague many steam generators around the globe.

While underdeposit corrosion (UDC) can occur underneath a variety of precipitates, porous iron oxide deposits usually have the greatest influence. This explains the low iron limits shown in Table 1. Iron particulates are generated by condensate return and feedwater system corrosion, sometimes by the carbonic acid attack as outlined earlier, but also by oxygen attack. This is a clear example of how one form of corrosion has potential manifestations for other corrosion mechanisms.

The following example illustrates the effect of organic impurities on steam chemistry. Author Buecker once evaluated a fouling issue at an organic-chemicals plant that produced a primary product and four derivatives thereof. Steam was generated by several 550-psig package boilers in which solids deposition in the superheaters (and associated tube overheating) required tube bundle replacements every 1.5 to 2 years. An extracted superheater-bundle inspection revealed internal deposits up to 1/4 in. in depth. The inspection team also discovered foam issuing from every boiler saturated-steam sample line. The plant had minimal analytical chemistry capabilities with no trained water chemists on staff, but a condensate return data review provided by the plant's water treatment vendor showed total organic carbon (TOC) concentrations as high as 200 ppm. Compare this to the recommended upper limit of 0.5 ppm, as shown in Table 1. The excessive organic contamination in the boilers generated the foam that carried over to the superheaters.

Beyond a "water is water" philosophy, some plant managers are reluctant to install condensate polishers because of cost and the extra personnel needed to operate the equipment. However, such an investment can pay large dividends by minimizing or preventing boiler tube failures and corresponding equipment shutdowns. Ion-exchange polishing is a potential treatment option for condensate that contains inorganic ions, such as hardness, chloride, sulfate and similar elements and compounds. Temperature is an

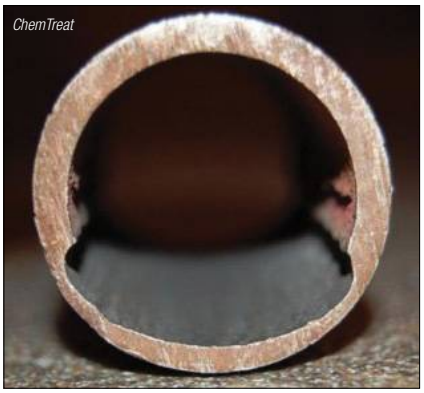


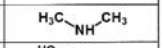
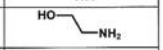
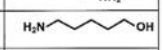
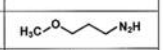
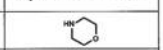
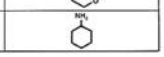

**FIGURE 4.** Shown here is carbonic acid corrosion of a carbon steel condensate return line. Besides direct attack, carbonic acid and other corrosion mechanisms release iron oxide particulate matter that can settle in boiler tubes to reduce heat transfer and initiate underdeposit corrosion (UDC)

**FIGURE 5.** Shown here is a sudden failure of a boiler tube from hydrogen damage. Notice the thick-lipped fracture, which indicates failure with little metal loss

important factor in treatment selection for these systems. Activated-carbon filtration may be effective for organics removal. Several are possible for particulate control, including direct filtration. The aforementioned boiler-makeup alkalinity reduction can reduce $CO_2$ transfer to steam and the potential for condensate carbonic-acid corrosion. Alternatively, carbon-steel corrosion is minimized by operating within a mildly basic pH range. Alkalizing amine feed for condensate and feedwater pH conditioning is common. These are small-chain organic molecules with an ammonia group attached to, or embedded within the compound (Table 2).

Selecting the best product or product blend is sometimes difficult, as each compound has a different basicity and distribution ratio (the tendency for the product to depart with steam or remain dissolved in the boiler water). It is desirable to have comprehensive pH control throughout the network, but a single compound may not be sufficient to achieve broad results. Recently commercialized blended amine products can provide wide-ranging coverage. A thorough analysis of system design, metallurgy, current chemistry, operating temperatures, and other parameters is a prerequisite for proper program selection, as it is for any other condensate polishing or treatment choice. Filming amines that directly protect metal surfaces have also been successfully applied in some applications, but space limitations prevent a discussion at this time.

**TABLE 2. COMMON ALKALIZING AMINE**

| Amine | Chemical Formula | Molecular Weight (g/mol) | Structure |
|---|---|---|---|
| Dimethylamine | $C_2H_7N$ | 45.08 |  |
| Ethanolamine | $C_2H_7NO$ | 61.08 |  |
| 5-Aminopentanol | $C_5H_{13}NO$ | 103.16 |  |
| 3-Methoxypropylamine | $C_4H_{11}NO$ | 89.14 |  |
| Morpholine | $C_4H_9NO$ | 87.1 |  |
| Cyclohexylamine | $C_6H_{11}NH_2$ | 99.2 |  |

Also note the low feedwater dissolved oxygen (D.O.) guidelines in Table 1. Depending on the application, D.O. control can be a thorny issue. For power-generating units with high-purity makeup and feedwater, research has shown that a small amount (5–30 ppb) of dissolved oxygen at the economizer inlet is necessary to minimize flow-accelerated corrosion (FAC). FAC has been an extremely concerning issue since the first observed FAC failure killed four power plant personnel in 1986 [*3*].

However, in industrial units with lower purity makeup and condensate return, D.O. must be maintained at near-zero concentrations to minimize iron and copper corrosion. A key piece of equipment is a mechanical deaerator, which, when functioning properly, will reduce D.O. to approximately 7 ppb. Additional oxygen reduction is achieved with reducing agent/oxygen scavenger feed. Over time, deaerator trays and spray nozzles can become misaligned or damaged, which may be overlooked by plant personnel. On-line dissolved oxygen monitoring is just one part of a comprehensive sampling and analysis program [*4*].

## Boiler-water treatment

The boiler has the harshest conditions within a steam-generating system, and chemistry excursions can easily lead to rapid corrosion or other problems. In power boilers, which typically receive consistent high-purity makeup, the primary issue is pH control to minimize carbon-steel corrosion. Table 1 outlines the typical mildly basic ranges that are optimal for many boilers.

Tri-sodium phosphate ($Na_3PO_4$) is still commonly employed for pH control in both industrial and many power boilers.

$$Na_3PO_4 + H_2O \leftrightarrows Na_2HPO_4 + NaOH \qquad (8)$$

Knowledge beyond this basic concept can be lacking at plants without trained water chemists. A prime example is in systems where hardness and silica may periodically or regularly enter the boiler via contaminated condensate. Without proper chemistry control, these constituents can form very tenacious calcium and magnesium silicate scales that are extremely difficult to remove. In large measure, it was this chemistry that influenced the development of phosphate treatment with accompanying hydroxide alkalinity. Phosphate and hydroxide alkalinity react directly with calcium to produce calcium hydroxyapatite:

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$$10Ca^{2+} + 6PO_4^{3-} + 2OH^- \rightarrow 3Ca_3(PO_4)_2{\cdot}Ca(OH)_2\downarrow \quad (\mathbf{9})$$

Magnesium and silica react with hydroxide alkalinity to form the non-adherent sludge serpentine:

$$3Mg^{2+} + 2SiO_3^- + 2OH^- \rightarrow 3MgO{\cdot}2SiO_2{\cdot}2H_2O\downarrow \quad (\mathbf{10})$$

These two compounds exist as soft sludges that are much easier to remove than the hard scale that would otherwise form. The materials typically settle in the mud drum or lower headers and are removed by blowdown. Careful analyses and system chemistry evaluation are necessary to design and operate the chemical feed systems to maintain proper conditions. Various synthetic polymers have been developed to assist with hardness and iron oxide deposition control. These compounds cannot be introduced arbitrarily to boilers, but must be selected and dosed based on rigorous chemistry evaluations. Some polymers are better at sequestering hardness ions, while others are more effective in controlling particulates. No "one size fits all" exists.

How plant personnel handle boiler chemistry upsets may generate additional problems if incorrect procedures are followed. For instance, the reaction shown in Equation (6) illustrates that some chemistry excursions can lower boiler pH significantly and quickly. As pH drops below 8.0, steel corrosion rapidly increases. The best procedure in such cases is to kill the boiler fires, increase blowdown, drain the boiler when safe, and eventually refill it with fresh, treated water. Before restart, it is imperative to find and correct the contamination source. However, these procedures may curtail plant production, which can cause management angst. A "knee-jerk" alternative is to keep the boiler in operation and inject caustic to raise the pH. Unfortunately, the rapid pH elevation induces precipitation of the recently-generated iron corrosion products, which settle on the boiler tubes and add many more locations for future underdeposit corrosion.

## A final note

All systems are different, and, as with all other technologies, due diligence is necessary to determine the feasibility of utilizing these methods. Always consult your equipment manuals and guides. Also, reputable chemical vendors can offer the products to achieve your goals. ■

*Edited by Gerald Ondrey*

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# Precoat Filter Demineralizers in Steam Loops

By minimizing, or even eliminating, the need for blowdowns in steam systems, precoat filter demineralizer systems can greatly contribute to water-conservation efforts

**John Yen**
Marmon Industrial Water LLC

## IN BRIEF

CONDENSATE CONTAMINATION

THE HIGH COST OF BLOWDOWNS

RECOVER CONDENSATE

WATER CONSERVATION

ENHANCED STARTUP AND EFFICIENCY

Steam is essential in any chemical process plant, primarily for generating heat and power. Power generation (the largest consumer of industrial water) and water-dependent thermal plants generate more than 81% of the world's electricity using steam to rotate an electric generator. The steam can be generated in various ways, which include: by coal-fired boilers; waste heat from gas- or oil-fired turbine generators; and by direct or secondary generation in a nuclear reactor.

Because demand for electricity also drives demand for water, in a time when water as a resource is becoming less predictable and more stressed, power outages caused by water shortages are becoming a realistic threat. To help themselves out of this quandary, power plants, and other industrial plants that generate steam, stand to benefit from investment in technologies that conserve and make the greatest use of water.

## Condensate contamination

The condensate water that results from steam-turbine operation is one area where water conservation can be realized. For both boilers and heat-recovery steam generators (HRSGs), condensed water collects in the system and can be reused. However, this fact is complicated by the fact that, over time, the condensate in the steam loop becomes increasingly contaminated, which will cause damage to plant components. This includes boilers, steam generators, reactors and turbines. Untreated condensate can damage the steam turbine by erosion through the impingement of abrasive particulate matter transported with the steam, or by deposition of soluble material, such as silica and copper, on the turbine blades. Other damage caused by contamination can include tube pitting, tube rupture and drum pitting (Figure 1). Contamination of boiler feedwater and condensate occur from four principal sources, as follows:

***Makeup-water system leakage.*** Dissolved and colloidal solids that pass through the makeup water system can often cause contamination.

***Condenser leakage.*** Mainly dissolved, including some suspended, solids can leak from the condenser. The amount of such solids is dependent on the condenser design, level of maintenance and the quality of cooling water present on the tubeside. In the case of seawater-cooled systems, the smallest leak can become a significant problem for high-pressure boiler systems.

***Metallic corrosion.*** Metal-oxide-based suspended solids are created within the boiler steam cycle as byproducts of corrosion. These metal oxides are usually forms of iron oxide, but oxides of copper, chromium and nickel can also contribute.

***Startup contaminants.*** Silica is a notorious contaminant due to its frequent presence during initial boiler startup, typically as residue from the system manufacture and assembly.

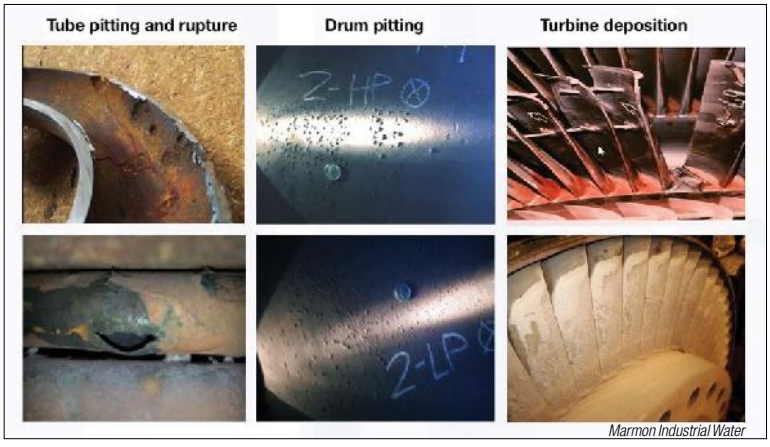


**FIGURE 1.** Contaminated condensate can lead to several types of costly damage

**FIGURE 2.** A precoat demineralizer system can help to remove contaminants from condensate streams, making water reuse more economical

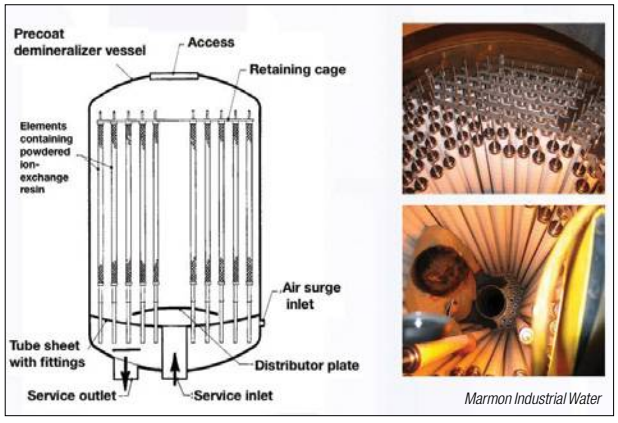


**FIGURE 3.** A precoat demineralizer system combines filtration elements and ion-exchange resins within a specially designed process vessel

## The high cost of blowdowns

The traditional method of removing contaminants is a blowdown, which involves essentially purging all the water from the condensate loop at once and replacing it with fresh water. For large plants, this can amount to tens of thousands of gallons of water per blowdown. This loss of water has numerous associated costs, not just due to the cost of fresh replacement water, which is rising steeply across all regions, but also the costly steps required to make it ready to convert into steam. These steps can include pre-treatments, such as clarifying, filtration, softening, dealkalyzing, reverse osmosis and deionization, and chemical treatment, such as neutralizing amines. In addition, the largest cost comes from the energy to heat the water. It takes 1 Btu of heat to raise 1 lb of water by 1°F, and while the temperature of condensate typically hovers around 200°F, makeup water usually enters the system at 55°F. The cost of fuel required to raise the temperature of water by 145°F is significant. Furthermore, there are significant wastewater-treatment costs associated with dumping the dirty condensate, as detailed in Table 1.

## Recover condensate

One technology that offers a viable solution for minimizing blowdowns is a precoat filter demineralizer (Figure 2). This is a condensate polisher that removes contaminants from condensate while preserving the heat, allowing it to return to the process clean and warm.

Precoat filter demineralizers combine two distinct technologies: ion-exchange and filtration in one vessel or application. They remove contaminants that are present in the steam condensate cycle by removing suspended solids using filtration and reducing ionized impurities to the parts-per-billion (ppb) range, and in some cases, to parts-per-trillion (ppt) levels. Precoat filter demineralizer systems are essentially vessels with similar filter septa to those used in pre-filters or condensate filters, but are specially designed to act as a support for a precoat material. Figure 3 illustrates the different parts of a precoat demineralizer vessel. Premixed resins available in various cation and anion ratios, with or without

**TABLE 1. ESTIMATED COST OF BLOWDOWNS PER 1,000 GAL**

| Fresh water | Makeup water treatment | Chemical treatment (neutralizing amines) | Energy to heat | Wastewater treatment of purged water | Total cost, per 1,000 gal |
|---|---|---|---|---|---|
| $0.30–0.50 | $0.34–0.50 | $0.15 | $5–10 | $2–4 | $7.80–15.15 |

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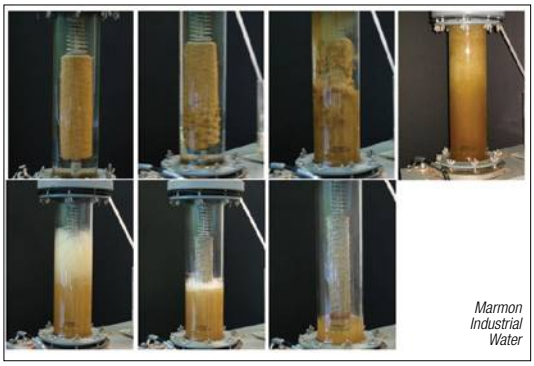


**FIGURE 4.** The filter elements are coated with resins to remove ionic contaminants and suspended solids, including iron, copper and silica. Once the resin is exhausted, the elements can be cleaned and re-coated

fiber material, are coated on the outside of the filter septa in a thin layer. These finely ground resins remove ionic contaminants while also effectively removing most suspended solids. Upon exhaustion (ion breakthrough) or high pressure drop (solids loading), the unit is backwashed, sending the exhausted precoat and contaminants out to drain. Subsequently, a new precoat is applied and the process is repeated.

Precoat filter demineralizers remove iron, copper, silica, activated corrosion products and salts, whether soluble or suspended. Systems of this type have been in operation since the early 1960s, but have experienced advancements in precoating techniques, as well as improvements in a high-energy air-scour backwash for enhanced septa cleaning, reducing waste volumes by over 60% in certain applications. Figure 4 illustrates the progressive coating and cleaning process of the filter elements.

## Water conservation

Using precoat filter demineralization provides a string of benefits, starting with water conservation. By avoiding blowdowns, plants can save millions of gallons of water per year, as well as the costs associated with treating both blowdown water and makeup water, including the related labor costs. There are also growing regulatory compliance implications, especially in water-stressed areas. Some plants are already facing increased pressure to reduce water waste, and every other plant should be preparing now for this eventuality.

But even in the absence of regulation, there are stout economic advantages to installing this kind of condensate polisher. A large cost benefit is that precoat filter demineralization helps protect assets. Less contaminated water will result in less damage to system components, extending the life and performance of those components and reducing maintenance requirements. Plants that do not install a condensate polisher may save money in the short-term, but pay more in the future for equipment damage, boiler cleaning and replacement fees. Though many natural-gas combined-cycle (NGCC) plants are still relatively new, corrosion has already become nearly ubiquitous in steam boilers and heat-recovery boilers in those plants without high-quality condensate-polisher systems. Furthermore, the air-cooled condenser (ACC) design paradigm contributes substantial corrosion-product contamination to cycle water. Data from the Electric Power Research Institute (EPRI; Palo Alto, Calif.; www.epri.com) indicate that four of the top five causes of HRSG tube failure have been tied to steam-cycle chemistry related to flow-accelerated corrosion, corrosion fatigue, under-deposit corrosion and pitting.

Returning more high-quality condensate back to the boiler system can improve feedwater quality, increasing the number of boiler cycles of concentration, faster startup times and extending the time between blowdowns.

For some plants, when it is time to replace their 40- to 50-year-old boilers, they are finding that manufacturers have more stringent condensate-quality requirements in order to protect the equipment from contamination damage. In these scenarios, plant engineers are turning to condensate polishers to help them maintain the water quality specified by the modern equipment.

## Enhanced startup and efficiency

For various maintenance and repair reasons, a turbine occasionally has to be taken offline. When this happens, the condensate in the system can become contaminated very quickly due to the stagnation of the water inside metal pipes, combined with the introduction of air into the system.

When the condensate is highly contaminated, a blowdown is required before the system can be restarted, significantly delaying the achievement of full generating capacity. During this startup delay, it can cost the operator between $25 and $35 per MWh — a substantial outlay each time the plant cycles. Further, chemistry fluctuations make it impossible to determine how long it will take for the plant to reach full power each time it starts, complicating budgeting for auxiliary power purchase. Systems that use a precoat filter demineralizer can avoid this blowdown, resulting in a process that can return the turbine to service much more quickly and less expensively. Additionally, the elimination and control of harmful impurities, both dissolved and insoluble, can improve thermal efficiency (by up to 1%) and can increase overall plant efficiency (by approximately 1–3%).

## Water scarcity will continue

While the cost of fresh water is among the smaller pieces of the total cost of makeup water, this is not likely to remain so. The average price of water increased by 60% in the 30 largest U.S. cities between 2010 and 2019, according to data compiled by Barclays, while California water futures have regularly jumped as much as 300% in recent years. The growing water crisis is requiring all industries to rethink their water use, especially those in essential service sectors that depend so heavily on water. ■

*Edited by Mary Page Bailey*

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# Predictive Maintenance Implementation

Five common mistakes associated with implementing predictive maintenance tools are discussed here, along with five ways to avoid them

**Bryan Christiansen**
Limble CMMS

Predictive maintenance (PM) implementation can be a daunting task. There are many factors to consider and many ways that things can go wrong. Therefore, it is essential to be aware of the most common mistakes to avoid them.

Predictive maintenance can turn into a nightmare without the proper implementation, leading to high costs and decreased productivity. This article discusses the five most common mistakes made during predictive maintenance implementation and gives advice on how to avoid them.

Most of the mistakes and solutions covered here slip under the radar because they are not always glaringly obvious. However, they can significantly impact the overall success of your PM implementation.

## Benefits of PM implementation

With the right approach, predictive maintenance can significantly benefit a business. PM tools, such as a computerized maintenance-management system (CMMS; Figure 1) have been beneficial in a wide range of sectors within the chemical process industries (CPI) and elsewhere, including manufacturing, transportation, power generation, healthcare, construction and oil and gas. The following are some of the advantages and benefits achieved with PM implementation.

***Increased equipment efficiency.*** The first and most apparent benefit of predictive maintenance is that it can help you keep equipment running at peak efficiency. By monitoring machines and catching problems early, plants can avoid the downtime and inefficiency that comes with waiting for a break to happen before fixing it.

***Reduced maintenance costs.*** Maintenance costs are one of the most significant expenses for most businesses. Fortunately, predictive maintenance has been proven to reduce these costs by identifying and repairing equipment failures before they cause a breakdown.

**FIGURE 1.** With the right approach, predictive maintenance can significantly benefit a business

***Increased production.*** Every company wants to increase production. After all, more products mean more money. However, it's not always easy, especially if they're working with a process that's not humming along nicely. Predictive maintenance can help increase production by finding and fixing minor issues before they turn into big problems.

***Decreased downtime.*** The main benefit of predictive maintenance is the decreased downtime it brings about. With accurate predictions, companies can schedule their maintenance activities to minimize the time that the equipment is unavailable.

This can mean shutting down equipment for preventive maintenance during low demand, such as weekends or nights. This shortens downtime and helps avoid the inconvenience and cost of having equipment unavailable during peak times.

***Improved safety and product quality.*** Predictive maintenance can help improve safety by reducing the likelihood of equipment failures that could lead to injuries. In addition, because predictive maintenance can help identify potential quality issues before they cause customer problems, it can also improve product quality.

For example, if a piece of equipment shows signs of wear, it can be repaired or replaced before it breaks down or causes an accident.

## Common mistakes & solutions

Every organization wants to get the most out of its predictive maintenance implementation, but often, things can go wrong. Therefore, it is essential to undertake the best predictive maintenance techniques and be aware of the most common mistakes to avoid them. The following are the five most common mistakes and their solutions.

***1. Making everything a predictive task.*** Predictive maintenance may thrive in a chemical factory since chemical plants appear to be the perfect setting for it. High degrees of automation and instrumentation and meticulous maintenance record-keeping provide abundant data for machine-learning algorithms.

Furthermore, most plants seek consistent operating conditions, making it easier to detect trends and patterns. There's the overall equipment effectiveness (OEE) factor. Improved reliability can directly and significantly impact a company's OEE.

However, it is essential not to make everything a predictive task — not every condition or problem lends itself to being predicted. For example, some problems are so intermittent that their symptoms may not be apparent until it's too late to do anything about them. The data may be too noisy to glean any insight from

other cases.

***Solutions.*** Before implementing a predictive-maintenance strategy, chemical plant owners should carefully evaluate what can and can't be predicted. They should only tackle those tasks that will provide significant value and avoid trying to make the impossible possible.

By doing this, they can create a best-in-class predictive-maintenance program that will optimize the chemical plants' equipment and overall equipment efficiency (OEE).

***2. Erroneous equipment selection and failure to update the system.*** Predictive maintenance can take chemical plant operations to the next level. However, the plant must have a sound maintenance-management system (MMS) in place to be effective.

An MMS is a crucial factor in achieving an efficient predictive maintenance program. It enables the collection and analysis of data so that CPI plant owners can identify trends. It also allows for the execution of planned maintenance tasks instead of relying on unplanned corrective maintenance.

However, an MMS is only effective if it is up to date. Outdated data can lead to erroneous equipment selections and prevent the plant from getting the full benefits of a predictive maintenance program.

It is also important to note that not every piece of equipment in a CPI plant needs to be monitored by predictive maintenance. The equipment selected for monitoring should be based on the plant's specific needs and the types of failures that are most likely to occur. A good starting point is to identify the critical assets in the plant and focus on those first.

***Solutions.*** To get the most out of a predictive-maintenance program, chemical plant owners must ensure that their MMS is up to date and accurate. They should also carefully select the equipment that will be monitored and focus on their critical assets first.

***3. Employing the wrong personnel and inadequate training.*** Employing the wrong personnel is another common mistake. This can happen if the required skill sets do not exist in-house or predictive maintenance is used to cut training costs. The best predictive maintenance programs use a combination of highly skilled personnel in their respective fields. Such a team should be able to work together to develop and implement the program.

If there isn't the right personnel in-house, the chemical plant manager may be tempted to cut costs by training existing staff members. However, this can often lead to inadequate training. The worst part about inadequately trained staff is that they can do more harm than good.

***Solutions.*** To avoid hiring the wrong and inadequately trained staff, the management can do the following:

- Hire personnel with the right skillset
- Ensure that team is adequately trained

*Hiring the right personnel.* There are a few things to keep in mind when hiring predictive-maintenance personnel. The first is that they should have experience in their respective field. This experience can come from working with similar machinery or predictive maintenance software.

Second, they should be able to work together as a team. Predictive maintenance is often a complex process requiring several different experts' input. Third, they should be able to communicate effectively — this means understanding and explaining complex concepts so that others can understand.

Fourth, they should be able to train others. As mentioned earlier, one of the main tasks of predictive-maintenance personnel is to train staff members on using the software and equipment.

*Ensuring adequate training.* To ensure that staff is adequately trained, management has to do the following:

- Set clear training goals
- Make sure that the training is interactive
- Use simulations where possible
- Make sure that the training is relevant to the job

One of the best ways to ensure that staff is adequately trained is to set clear training goals. For example, a goal for staff members could be the ability to operate the predictive-maintenance software by the end of the training session.

***4. Not analyzing and integrating collected data.*** It isn't efficient to just set and forget a predictive-maintenance program — data analysis is a crucial part of it. After all, the insights gleaned from data will help fine-tune the program and prevent issues down the line.

Analyzing data can be daunting, especially if there isn't a data scientist on staff. And even if there is, they might not have the time to constantly monitor the program's data for trends.

This is why hiring the right and adequately trained personnel is emphasized in point number three. If the right team is in place, they will be able to take on the task of analyzing data and integrating it into a predictive-maintenance program. Without proper data analysis and integration, a predictive-maintenance program will be nothing more than a shot in the dark.

***Solutions.*** To ensure adequate data analysis and integration, chemical plant managers can consider the following:

- Use data-visualization tools to better understand the data and to spot trends
- Automate data analysis as much as possible, using tools like machine learning and artificial intelligence
- Delegate data analysis tasks to team members skilled in data analysis and have the time to do it properly

While there is more to data analysis than what we've listed here, these tips will get managers started on the right track. Additionally, it's important to remember that data analysis is an ongoing process — the more data analysts have, the better their insights will be.

***5. Lack of consistency in predictive maintenance implementation.*** Consistency is an integral part of any maintenance program, and predictive maintenance is no exception. To get the most accurate results from a predictive maintenance program, data must be collected consistently and accurately.

This means having a plan in place for collecting data, appointing who will be responsible for managing it, and what processes will be put in place to ensure that data are collected accurately. Without a consistent approach to data collection, a predictive maintenance program will be less accurate and less effective.

***Solutions.*** Here are a few tips on how to maintain consistency in a predictive maintenance program:

- Establish a straightforward pro-

cess for data collection and make sure all stakeholders are aware of it
- Train all personnel involved in data collection on how to collect data accurately
- Use standardized forms and templates for data collection whenever possible
- Conduct regular audits of data collection procedures to ensure they are being followed correctly
- Put in place a system for monitoring and tracking data collection progress to identify any areas of improvement

Chemical plant managers can ensure that a predictive maintenance program is as accurate and effective as possible by following these tips.

## Final remarks

Predictive maintenance can fail because of reasons like over-predicting possible outcomes, lack of adequately trained personnel, inconsistency of predictive maintenance implementation, and not using collected data.

It is a powerful tool to help organizations improve productivity and avoid mistakes, and while it comes with its fair share of challenges, organizations can overcome them with the right strategies.

Implementation can be a smooth and successful process with in-depth knowledge and following needed steps: defining goals and objectives, assembling the right team, training personnel, choosing the right technology, consistent implementation, and tracking program success and making improvements accordingly.

By following the tips and solutions explained in the article, businesses can ensure a successful predictive maintenance implementation in their organization. Do not let common mistakes stand in the way of success. ■

*Edited by Gerald Ondrey*

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# Economic Indicators

2020 2021 2022

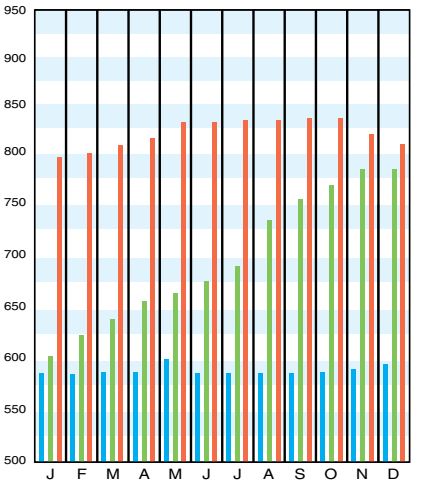
**Download the CEPCI two weeks sooner at www.chemengonline.com/pci**

## CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

| (1957–59 = 100) | Dec. '22 Prelim. | Nov. '22 Final | Dec. '21 Final |
|---|---|---|---|
| *CE* Index | 808.7 | 814.6 | 776.3 |
| Equipment | 1024.9 | 1033.2 | 977.9 |
| Heat exchangers & tanks | 851.4 | 861.7 | 830.2 |
| Process machinery | 1035.5 | 1041.1 | 975.8 |
| Pipe, valves & fittings | 1444.7 | 1461.7 | 1414.8 |
| Process instruments | 556.2 | 555.6 | 564.4 |
| Pumps & compressors | 1323.1 | 1323.1 | 1179.3 |
| Electrical equipment | 794.6 | 785.7 | 678.0 |
| Structural supports & misc. | 1137.2 | 1153.7 | 1059.4 |
| Construction labor | 358.7 | 359.1 | 347.6 |
| Buildings | 795.2 | 802.4 | 808.3 |
| Engineering & supervision | 311.9 | 311.8 | 310.8 |

Annual Index:
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5
2018 = 603.1
2019 = 607.5
2020 = 596.2
2021 = 708.8

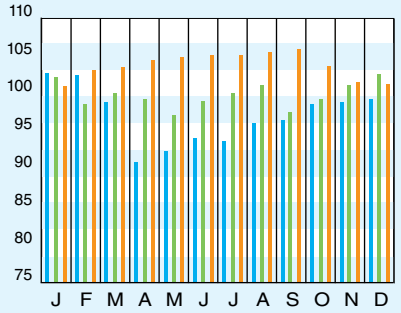
Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)



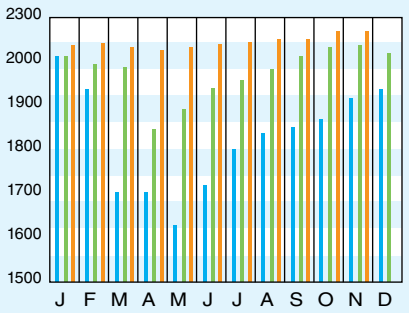

## CURRENT BUSINESS INDICATORS

| | LATEST | | PREVIOUS | | YEAR AGO | |
|---|---|---|---|---|---|---|
| CPI output index (2017 = 100) | Dec. '22 = 98.5 | | Nov. '22 = 99.7 | | Oct. '22 = 101.2 | Dec. '21 = 100.4 |
| CPI value of output, $ billions | Nov. '22 = 2,141.7 | | Oct. '22 = 2,190.2 | | Sept.'22 = 2,187.2 | Nov. '21 = 1,936.5 |
| CPI operating rate, % | Dec. '22 = 79.3 | | Nov. '22 = 80.3 | | Oct. '22 = 81.6 | Dec. '21 = 81.6 |
| Producer prices, industrial chemicals (1982 = 100) | Dec. '22 = 330.4 | | Nov. '22 = 341.9 | | Oct. '22 = 343.9 | Dec. '21 = 335.6 |
| Industrial Production in Manufacturing (2017 =100)* | Dec. '22 = 99.8 | | Nov. '22 = 101.1 | | Oct. '22 = 102.2 | Dec. '21 = 100.3 |
| Hourly earnings index, chemical & allied products (1992 = 100) | Dec. '22 = 204.4 | | Nov. '22 = 205.3 | | Oct. '22 = 204.0 | Dec. '21 = 194.4 |
| Productivity index, chemicals & allied products (1992 = 100) | Dec. '22 = 90.2 | | Nov. '22 = 91.8 | | Oct. '22 = 93.0 | Dec. '21 = 95.9 |

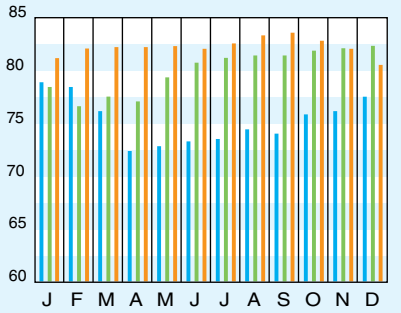
### CPI OUTPUT INDEX (2017 = 100)†




### CPI OUTPUT VALUE ($ BILLIONS)




### CPI OPERATING RATE (%)




*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2012 to 2017
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

## CURRENT TRENDS

The preliminary value for the *CE* Plant Cost Index (CEPCI; top) for December 2022 (most recent available) fell compared to the previous month's value. The current decrease is the sixth consecutive monthly decline, following a long string of increases between November 2020 and June 2022. The December 2022 preliminary values show decreases in the Equipment, Buildings and Construction Labor subindices, while the Engineering & Supervision subindex saw a slight uptick. The current CEPCI value now sits at 4.2% higher than the corresponding value from December 2021. Meanwhile, the Current Business Indicators (middle) show a small decrease in the CPI output index for December 2022.